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Electrical Progress in 1915

Undoubtedly the most spectacular advance in electrical engineering during the past year has been the development of the transcontinental telephone lines, followed shortly by the development of wireless telephony to such an extent that it has been possible to transmit the human voice through the ether from Arlington Heights, Va., to Honolulu, a distance of over 5000 miles, so successfully that the message was plainly heard at a distance of three feet from the receiver. A similar distance will allow transmission of speech from San Francisco to Japan and the Philippine Islands, or from Washington, D. C., to Paris, Berlin or Petrograd.

Aside from this rather spectacular achievement, the year 1915 is probably noteworthy more for its steady growth along all lines of electrical work than for any remarkable or sudden advances. Possibly the most notable example of the consistent growth in the size of electrical apparatus is evidenced by the purchase by the Commonwealth Edison Company of Chicago of a turbo-generator rated at 35 300 k.v.a., and by the purchase within the last few weeks of a similar unit rated at 47 000 k.v.a. by the Duquesne Light Company of Pittsburgh. It would appear that the electrical manufacturers are willing and able to build generating apparatus of almost any size for which there is a market, which in turn is limited by the amount of power which a central station is warranted in concentrating in one unit. This increase in size of units has been attended by an increase in efficiency, especially that secured in the steam unit by the use of highly superheated, high-pressure steam and the modern high vacuum condensers. A valuable feature is that, on account of the paramount importance attached to continuity of service, it has been deemed advisable with so much power concentrated in one machine to use even larger factors of safety than heretofore, so that these machines are of the utmost reliability.

The latter half of the year has been noteworthy for the remarkable increase in the demand for industrial motors of all sizes, reflecting the general improvement in industrial conditions. Most of these units have been of standard sizes and ordinary ratings, and they have very largely been applied to conditions which have become well standardized in the past. The increased demand, therefore, indicates primarily a growing appreciation on the part of the manufacturing industries of the advantages of motor drive as compared to other methods of power application. There have, however, been some installations of unusual characteristics, notably two 12 000 horse-power motors direct connected to reversing blooming mills, these being the largest motor-driven steel mills in the world. The efficiency and many incidental advantages offered by motor drive are such that it is now being adopted by the steel mills as a rule rather than as the exception. Coincident developments in control methods have been carried on until it is now possible, with suitable control apparatus, to adjust the speed of an induction motor independently of the load with all the accuracy and with almost the ease of a direct-current motor. The apparatus can be so arranged that the motor will develop either constant horse-power or constant torque over a wide range of speeds.

Another industrial development has been the increased application of direct-traction elevators for high-speed service, with improved types of unit-switch control, arranged to produce at once the highest possible safety and exceedingly smooth acceleration.

An interesting feature of transformer development has been the removal of the inherent limitation to the size of the self-cooled transformers by the application of external radiators. Transformers of this type have been installed and are operating successfully in sizes up to 5000 k.v.a., and larger sizes can be built whenever their use is warranted. This is only one feature of the general tendency which has been noted throughout the year to place transformer and switching sub-stations entirely outdoors, thereby securing a marked simplicity in the layout as well as a considerable saving in the cost of installation.

Electric railway development has been consistent throughout the year. Possibly the most spectacular feature has been the application of 5000 volts direct current to interurban trolley car service. In practical importance this development is at the present time far overshadowed by the exceedingly successful operation of the Norfolk & Western locomotives in heavy haulage service on the main line of the Norfolk & Western Railway and the successful application of high-tension single-phase power in the electrification of the congested Pennsylvania Railway station at Philadelphia. The successful operation of these two large systems, each of which involves principles of operation of motors and control—such as the phase-converter, changing single-phase power to three-phase, the liquid rheostat and the doubly fed motor—which had never before been applied on a large scale, affords a high tribute to the foresight and engineering ability of the engineers who are responsible for their construction.

The Automobile Industry

The application of electrical equipment to automobiles has grown very rapidly, but not more rapidly than the automobile business itself has grown. While a few years ago it was the unusual thing to have a standard, moderate-priced vehicle equipped with starting and lighting outfits, it is today the customary thing to have this equipment, and the prospective purchaser looks upon it as just as necessary and just as much a part of the car as the carburetor.

The growth of the automobile business is realized by few not directly associated with it, despite the wide publicity that is being spread broadcast by the manufacturers and their agents; therefore a few words here bearing upon facts in relation to this growth will make a fitting introduction to an issue of the JOURNAL devoted to the various phases of this industry.

The prospective sales of vehicles for the coming season, of the pleasure and general purpose types, will amount to over 1 000 000, and these are being distributed through some 16 000 legitimate dealers. Truck and bus production will probably number in the neighborhood of 25 000 units for the coming season. The roughly estimated total value of all classes, exclusive of such vehicles as motor cycles and aeroplanes, will be approximately $7 280 000 000. The exports this year, based upon the latest returns available, will total over $100 000 000 up to December 1. These figures include trucks and pleasure cars, the latter being only slightly less in value than for the previous season, which really means that more vehicles of this type were exported, the average sales price being much lower than in previous years and more value being given for the money, rather than a smaller number of cars being exported, as might be supposed at the first glance.

The automobile industry provides employment directly to over 450 000 persons, and if all accessory factories and their employees were considered, roughly 1 050 000 persons are dependent upon the automobile industry. But what shall we class as "accessories?" Certainly not raw materials, and in the above figure raw material or the partial fabrication of them has not been taken into consideration. If it will take the hides of, roughly, 750 000 cattle for the leather upholstering, not considering the millions of yards of fabrics for tops and other forms of upholstering than leather, and the trainloads of light hardware, etc., that enter into the construction of the pleasure or commercial vehicle, who shall estimate the total number of persons the automobile industry indirectly houses and feeds? It would take a fairly large clock factory to produce the 300 000 automobile timepieces that will be demanded for the next season's production of automobiles.

Without going into details about the automobile tires that will be needed to supply new and old vehicles, it may be said that more than 7 250 000 tires will be produced.

Perhaps the figures collected to show the extent and scope of advertising may not stagger the American readers who are accustomed to talking in millions. Probably the popular advertising of vehicles and accessories in daily, weekly and monthly mediums will reach a net total for minimum space value of upwards of $4 750 000 for the coming year. One famous weekly medium claims to have space already signed up for over $2 000 000. In addition, the millions of catalogues printed and distributed, and the outdoor advertising, such as signboards, posters, etc., should be considered, which in addition to other forms of advertising furnish employment to many hundreds of people. Its cost is almost impossible to estimate accurately; doubtless it will be another $4 000 000 a year.

Consider the banker: As usual, he gets something more than a living from the automobile business. The total value of all cars produced and the materials manufactured for them passes through his hands in the form of cash many times from the production of the raw to the finished product, from the maker to the user, and of course banking percentage in these transactions is perfectly legitimate.

In spite of the tremendous increase in the production of pleasure vehicles, it appears at this time that all the manufacturers have in prospect more business than their estimates of six months ago led them to expect, and there is a wild scramble for materials, tools and buildings to meet the demands at home and abroad, many makers planning to double their output for the coming season. It is wonderful, in the face of the rapidly rising material market, that the automobile manufacturers continue to supply vehicles at such extremely moderate prices, specifications considered, and it is not idle talk to say that many of the agents of these customers are advising their prospective customers to place orders early if they are to receive deliveries and protect themselves against a possible advance in prices.

Regarding the electrical equipment of gasoline-propelled vehicles—the subject primarily under consideration—these devices are now of prime importance to everyone, from manufacturer to user, and the apparatus supplied by the electrical manufacturers of this class to the automobile manufacturers has a total value of $20 750 000, roughly speaking.

It is about time that the electrical journals of this country gave thought and space, and careful attention to this business, representing, as it does, a large factor in electrical manufacturing in units and volume, if not in the same percentage of relation to the dollar value. It is clear that the publishers of the JOURNAL are thoroughly aware of the situation, and appreciate that the reader of almost every trade publication is in all probability an automobile owner or would like to be one. And it is probable that the electrical magazines of the country have a higher percentage of readers and subscribers who are in a financial position to own an automobile than would be found among the subscribers to most other trade publications.

G. BREWER GRIFFIN

The Electric Vehicle

The electric passenger automobile has been considered generally by the public as a pleasure or social car to be used by women only, because it is the safest, easiest and most reliable type of car for a woman to drive, but this opinion was first shaken and then dispelled by the comparatively large number of business and professional men who have found that the electric car fulfills all the requirements of city service with respect to speed, range and cost of operation, and have adopted such a car for their own use. However, the introduction of auxiliary electrical equipment, such as electric lighting and starting, and its general use on high-grade gasoline cars has tended to obscure one of the merits possessed by the electric passenger car, that is, the cost of maintenance. In this issue Mr. Gail Reed has recorded the maintenance costs of electric cars, which compare very favorably with those of the better class of gas cars which any successful business or professional man would choose as conveying a correct impression of himself. Mr. Reed does not mention the relative depreciation in the electric car and the gasoline car, but one finds it difficult to leave the subject without, at least, calling attention to the superiorty of the electric car. Notwithstanding the favorable position of the passenger car, the field of greater opportunity for the promotion of the electric vehicle industry lies in the use of trucks for transporting commercial goods, and here the demand is for small and moderate capacity delivery wagons rather than very large capacity trucks or drays. This field is very extensive, and as yet has been scratched only, but rapid progress is being made, as is evidenced by the economical and satisfactory operation of large fleets of electric vehicles such, for example, as in the department stores of Gimbel Brothers in New York, Wanamaker in Philadelphia, Marshall-Field in Chicago; the bakeries of Ward in New York and Brooklyn, and Ward Brothers in Rochester and Buffalo; the Adams and American express companies in practically all the large cities in their territores; many of the larger brewers, such as Jacob Rupert in New York; practically all of the larger central stations, notably the Commonwealth Edison Company, the Edison Illuminating Company of Boston, the New York Edison Company, the United Electric Company of New York, the Public Service Corporation of New Jersey, and the Duquesne Light Company of Pittsburgh; and the Curtis Publishing Company and many other establishments owning and operating smaller fleets.

The electrical equipments are constructed and have characteristics—especially the storage batteries as elucidated in articles by Mr. J. H. Tracy and Mr. E. J. Ross, Jr., in this issue—such that they can be cared for best by skilled attendants. All of the concerns cited hereinbefore have large enough fleets to warrant private garages with suitable charging equipment and skilled attendants. There are, moreover, numerous electric trucks operated by concerns whose business is not of sufficient volume to warrant a private garage and skilled attendants. Such truck owners have found that they can secure adequate and dependable service from various public garages, with the added advantage to the vehicle operators that they can foretell exactly what the cost of their delivery service will be, as the garages almost invariably make a uniform charge per month for storing and charging the cars, which is generally independent of the number of miles traveled per day. Public garages of this type require a much more diversified class of equipment than do the private garages, as it is necessary for them to provide charging equipment to care for all types and capacities of storage batteries, as is fully explained by Messrs. Schoepf, Candy and Brackett in their articles in this issue.

For such establishments as do not care to give as much supervision to an electric truck as is required for the charging and care of the batteries, the battery rental scheme which has been introduced in New York, Chicago, Boston, Baltimore and other cities is proving very attractive, as the payment of a moderate charge provides for a fully charged battery in good operating condition to be placed in the car at any time.

The most recent interesting development in the electric vehicle field is the electric taxicab which has been introduced so extensively and successfully in Detroit. The owner of the electric taxicab is attracted by its economical operation and dependability, and the user is attracted by its cleanliness and freedom from obnoxious fumes and noises.

The use of self-propelled vehicles equipped with storage batteries is rapidly spreading into many fields, such as small burden-bearing trucks and tractors and narrow-gauge locomotives in industrial works, and locomotives in gathering service in coal mines and haulage in metal mines. Under a recent ruling of the Interstate Commerce Commissioners railroads are required to make a charge for shifting or "spotting" cars on a privately owned siding or spur, so that many works of moderate or considerable capacity are purchasing storage battery locomotives for this service.

The importance of the development of the electric vehicle business to the central stations cannot be overestimated. An idea of its present size may be obtained from the following investment figures taken from the N.E.L.A. report for 1915:—Express and transfer companies, $3 010 000; public service companies, $3 671 000; department stores, $5 627 000; packing house organizations, $609 000; brewers, $5 350 000; wholesale merchants and manufacturers, $2 088 000; United States Government service, $435 000.

As pointed out by Mr. Gilchrist, in this report no other load that the central station can secure is so essentially off-peak in character, as the natural time for charging a commercial truck is exactly that time at which the central station's load is smallest. The load-factor of the average charging equipment is very high, ranging from 25 to 40 percent on a 24 hour basis, and the total income to be secured is very large.

J. M. Curtin.

Lighting and Starting Systems

FROM THE CAR MANUFACTURER'S STANDPOINT

D. G. Roos
Engineering Dept.,
Locomobile Company of America

THE motor car manufacturer who is about to decide upon an electric lighting and starting system finds himself confronted with a number of questions, all of which have an important bearing on his selection of equipment.

1—The voltage of the systems he is to employ.

2—The size, type, capacity and location of the storage battery.

3—Whether the single unit or motor-generator set shall be used, and the type of regulation to be used on the generator.

4—The application of the starter and generator units to the power plant of the car.

5—The style of wiring, switch details and electrical fittings to be used.

These various points will be discussed briefly along with a few of the vital considerations which should govern the selection of the most desirable equipment.

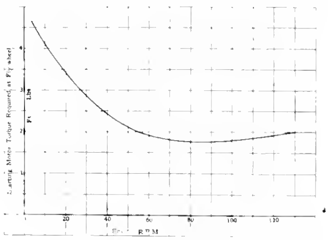

FIG. 1—MOTOR TORQUE CURVE

Showing torque needed to sustain a given speed with standard gearing, 20 : 1, with throttle open and motor well limbered up

THE SELECTION OF VOLTAGE

The most widely adopted standard of voltage is the so-called six-volt system, based on the three-cell storage battery, whose voltage is about 6.3 to 6.6 volts on open circuit. This system is first due to the fact that six-volt lamps were the first standard miniature lamps available in quantity and variety, and that six volts was the standard for ignition. When starters came on the market there was a tendency to higher voltages, 12, 18 or 24 volts, and lamps were burned in series. The generally accepted argument for this was that six-volt starting motors could not be built that were sufficiently light, powerful and efficient to crank the large engines. Undoubtedly high voltages simplified the starting problem and produced high cranking speeds, with relatively small motors. But when it is considered that a six-cylinder, 4½ by 5½ inch engine may be cranked at 120 r.p.m. with a six-volt motor weighing 34 pounds net, and having an efficiency of 71 percent, it is readily seen how erroneous the first impressions were in regard to the possibilities of the six-volt system.

The fact that six-volt lamps were alone available produced bi-voltage systems; six volt lighting, twelve volt starting, or even 18 and 24 volt systems with three-wire systems of wiring. The bi-voltage idea is losing ground, and as twelve-volt lamps are available, the tendency is to use either a straight six or twelve volt system, with the majority using six volts.

From the battery standpoint, six volts is more desirable. The battery is about 20 percent lighter for a given watt-hour capacity. There are only three cells to look after. The number of plates per cell is greater, so that the failure of one or more plates does not have so marked an effect in reduction of capacity or increased internal resistance. The space occupied by the twelve-volt battery is larger than that occupied by the six-volt battery. These points the manufacturer may waive, in

TABLE I

Weight		Capacity in Watt-hours		Cost	
Voltage		Voltage		Voltage	
6	12	6	12	6	12
50	71	480	420	$25.50	$33.00
60	86	624	672	29.00	37.00
80	101	918	960	36.00	42.00

consideration of faster cranking speed with the twelve-volt system, smaller amount of copper required for wiring, reduced losses in fittings, etc., from voltage drop. Table I gives a comparison of six and twelve volt batteries of nearly the same watt-hour capacity at forty-minute rating.

THE STORAGE BATTERY

Capacity—In choosing a storage battery the car manufacturer should select one of as large capacity as space, weight and price limitations will permit. Large capacity in the storage battery is an advantage from every angle except perhaps the cost of renewals to the customer.

1—It gives better voltage regulation, the internal drop in voltage being less as the capacity is increased. The counter e.m.f. is not so high with a given charging rate. The voltage regulation at the lamps, therefore, is better, being held more nearly within the prescribed limits, even though a constant current regulation is used on the generator.

2—The larger the battery, the less is the danger of the system going dead in cold weather. The capacity of the average lead battery at zero F. is about 50 percent of its capacity at 70 degrees, carburetor conditions are correspondingly bad, and the engine is stiffer than when warm. A large reserve in capacity is a good thing to

have under these conditions. A safe rule is to provide a battery which will crank the engine *thirty minutes or more at 70 degrees, engine and battery temperature.*

The Style of Battery—This should be a standard assembly, so that a customer can readily have it repaired or replaced. A freak or non-standard assembly should never be used for the purpose of stowing away the battery out of sight. The battery should be bought of a reputable and experienced concern, one having *service stations* in every territory where there are customers.

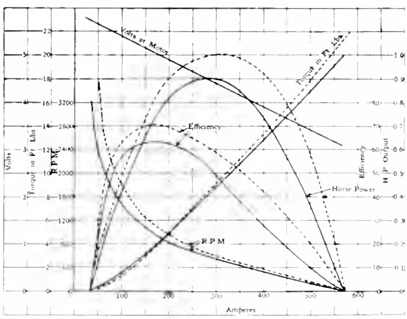

FIG. 2—COMPARISON OF MOTOR-GENERATOR STARTING CHARACTERISTICS WITH THOSE OF A SEPARATE UNIT STARTING MOTOR

Full line, motor generator; dotted lines, separate unit.

The Location of the Battery—This should be such that it is *readily accessible for inspection.* This is vitally important. The operators will neglect the battery if it is too difficult of access, and the entire system will be blamed. The battery should be fastened securely, otherwise jarring will quickly destroy it. The mounting should be such that there is no danger of corrosion of the supports from acid fumes, nor should it be possible for a short-circuit to do any serious damage to the car. The battery should never be held down with wedges. This strains the battery box and does not properly hold down the battery. The proper method is to hold the battery down by the handles firmly. The holding hooks or screws should be insulated from either the battery or the chassis.

CONSIDERATIONS GOVERNING THE CHOICE OF A STARTING MOTOR

It is generally conceded that better weight economy and efficiency can be obtained if a separate motor and generator are used. A motor-generator must be a compromise in design, unless the armature is run at vastly greater speed as a generator than as a motor. It is practical for small installations to do this and get good results, especially if "inherent current regulation" is used for controlling the current output as a generator. Such motor-generators are usually geared 2.5 or 3 to 1 with the engine crank shaft.

For large engines the weight of the motor-generator of requisite starting torque becomes enormous and it becomes necessary to use larger reduction in the gearing and run the armature at more nearly the same speed—as a motor and generator. This immediately reduces the efficiency of the machine and it becomes an advantage to use two separate units. In case "voltage regulation" is desired for controlling the output as a generator, there is no choice; the advantage is all in favor of the separate units. Table II gives comparisons for equipments for a six-cylinder $4\frac{1}{2}$ by $5\frac{1}{2}$ engine. Here is shown a distinct advantage of weight and efficiency in favor of the separate units, as against a motor-generator. If the

TABLE II

Single Unit Motor-Generator		Separate Unit	
Gearing as a motor	20–1	Gearing of motor	10–1
Gearing as a generator	$1\frac{1}{2}$–1	Gearing of generator. .	$1\frac{1}{2}$–1
Weight, lbs	76	Weight of motor and 10-1 gears lbs.	34
Weight gears and shaft, lbs	18	Weight of generator, lbs.	30
Total weight, lbs.	94	Total weight, lbs..	64
Percent efficiency of motor.	65	Percent efficiency of motor	71

generator is shunt wound and has voltage regulation, its efficiency is higher than a generator of the bucking coil type so that, if this type of regulation is chosen, it will further reduce the weight of a generator of given capacity. This type of regulation cannot be used in a motor-generator without greatly increasing its weight. It requires double field windings, double armature windings and two commutators with loss in generator and motor efficiency, and a great increase in size. This is shown by the fact that nearly all systems using the single unit (motor-generator) are using differentially compounded fields and inherent regulation, while on separate unit systems, the tendency is to voltage regulation with some form of shunt field control. Fig. 1 shows the comparative performance of a motor-generator starting characteristics and a separate unit starting motor, both of the same rated capacity.

The engine flywheel type of motor-generator is not gaining favor. There is no saving in weight, but a distinct loss. Commutating speeds are high, numerous sets of brushes are used, with consequent added probability of trouble. The armature is "overhung" and direct-coupled to a reciprocating engine, a practice never attempted successfully in the field of power engineering. The entire apparatus is exceedingly difficult of access, difficult of repair and difficult of replacement.

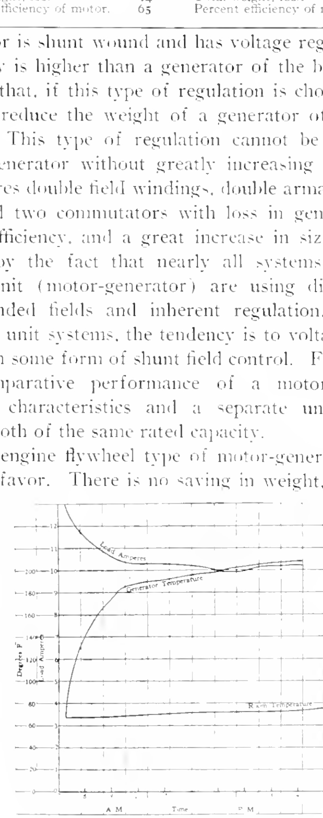

FIG. 3—CHARACTERISTICS OF INHERENT CURRENT REGULATED GENERATOR

For small, high-speed engines, a motor-generator may be selected geared 2½ or 3 to 1 by chain or gears, but for medium or low-speed engines the individual unit system should be used. The use of separate motor and generator permits the ready removal or replacement of one unit without affecting the other. The cost of replacement or repairs is less to a customer than a combined unit. The installation should be made so that either unit is readily removable.

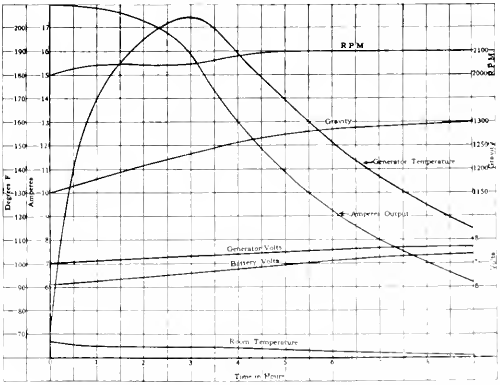

FIG. 4—CHARACTERISTICS OF A VOLTAGE REGULATED GENERATOR
In a nine-hour general performance run.

The high-grade car manufacturer always regards the starting motor and lighting generator as external accessories, and as a rule does not favor building them into the engine. For this reason flywheel geared applications of starting motors are increasing, while driving through the timing gears or by chain with overrunning clutches is losing favor. Transmission applications are also receiving some degree of popularity. The generator is usually driven from the the timing gears and is made readily removable, like the magneto. This is good practice. To build the generator or starting motor into the engine ties up the entire car while either one is removed, and in case of a breakage the damage to the entire engine may be serious. No manufacturer should employ a starter having a lower ratio of stalling torque to running torque than 6 to 1.

Double reduction starting motors are frequently used, having ratios of from 15 to 1, or 30 to 1. A great step in advance, from the car manufacturer's point of view, was the development of the high-torque, low-speed motor, which permits meshing the starting pinion direct to the flywheel at about 10 to 1 reduction, or lower. This makes an ideal installation, simple, much more quiet and more efficient than the double reduction installation. The gear meshing may be fully automatic, as with the screw type or Bendix method of meshing,; or it may be magnetic, as in the Westinghouse and Rushmore type of machines. The flywheel teeth and starter pinion teeth should be cut at a slight angle when magnetic meshing is used—about 13 degree pitch on the teeth. This has the effect of drawing the pinion in mesh when the starter is driving the engine, and of kicking it out of mesh when the engine tries to drive the starter. Overrunning clutches are eliminated in this type of installation. Intermediate resistance contacts are also eliminated and the enmeshment of the gear is perfect.

1—The cranking speed, determined from the torque resistance and r.p.m. curve of engine, should be fast enough for proper carburetor and ignition functioning.

2—Motor should have a stalling torque of from five to eight times the torque required to keep the engine turning at cranking speed.

3—In deciding on the application of the starter, consider accessibility, quietness and simplicity.

Cranking Speed—Good judgment must be used as to the reduction between the starter and engine crank shaft. It depends, first, on the starting motor characteristics; second, on the battery capacity, and third, on the torque resistance of the engine. In winter the battery capacity is low and the engine resistance is high, so a large margin of reserve torque, from six to eight times as great as the normal torque required to keep the engine turning, should be allowed for in gearing. At the same time the cranking speed must be high enough to obtain a magneto spark and aspirate gas from the carburetor.

Magnetos will give a spark at as low as 90 r.p.m. and nearly all carburetors will aspirate at that speed. A primer facilitates starting. The manufacturer must reach a compromise between cranking speed and reserve starting motor torque. Cranking at high speeds (150 r.p.m. or over) is a waste of energy and requires a needlessly heavy starting motor. Every car manufacturer should make a curve of his engine similar to that shown in Fig. 1. This shows the mean torque resistance of a six-cylinder engine, 4½ by 5½ inch, at various speeds with open throttle. The curve shows the lowest torque between 60 and 120 r.p.m. The torque increases rapidly below 60 r.p.m., and rises more slowly as the speed increases above 120 r.p.m. It is evident that the most economical cranking speed lies in the region between 60 and 120 r.p.m. for this motor and a flywheel torque of 35 foot-pounds. This being known, the manufacturer of the car is in a position to select gearing and specify

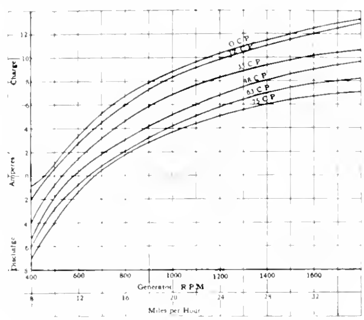

FIG. 5—BATTERY PERFORMANCE CURVES
With an inherent regulated current generator.

the torque-speed characteristics required. For this particular motor a starter was used having a cranking speed of 120 r.p.m., 10 to 1 reduction and a stalling torque of 22 foot-pounds, or on the engine crank shaft 220 foot-pounds torque.

CONSIDERATIONS GOVERNING GENERATOR SPECIFICATIONS

With reference to the characteristics of the generator, whether the generator is also the starting motor or whether it is a separate unit, the speed at which the generator "cuts in," that is, commences to charge the battery, should be as low as possible, not over ten miles per hour car speed under any conditions. The characteristics of the generator selected will depend upon,—

1—The size of the storage battery.
2—The lamp load.
3—What type of regulator is used.

The Size of Battery—In general a good way to attack this problem is to assume that a tourist might start out in the morning with a battery about 80 percent discharged. The generator should be capable of charging

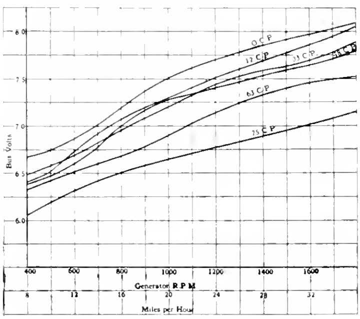

FIG. 6—VOLTAGE REGULATION CURVES
Of an inherent current regulated generator.

the battery fully in a day's run of two hundred miles in, say ten hours, averaging twenty miles per hour, assuming the following six-volt battery capacities in ampere-hours:—

Battery Capacity.	*80 Percent Discharge.*	*Generator Capacity.*
150	120	12
120	96	9.6
100	80	8
90	72	7.2

These generator capacities represent the average ampere-hour output of the generator required on a steady ten-hour run. Neither the "constant current" type of generator nor the "constant voltage" type gives a steady ampere output with continuous sustained running.

THE EFFECT OF THE TYPE OF REGULATION ON GENERATOR CAPACITY

The "constant current" generator has a "heat coefficient" and it gradually tapers its charge as the generator temperature rises. This is illustrated by the curve shown in Fig. 3. Here the generator starts at 13 amperes, but soon tapers to a steady charging rate of approximately 10.2 amperes. The mean average output in amperes per hour on a basis of the ten hours is 10.56 amperes. Therefore, from the point of battery capacity this generator would be suitable for use in connection with a 120 or 130 ampere-hour battery.

If a generator of the voltage control type is used the characteristics are different. Fig. 4 shows a voltage

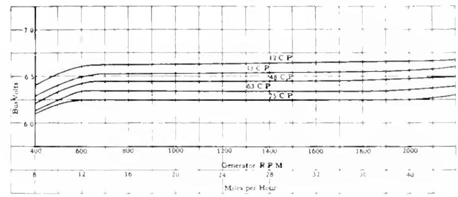

FIG. 7—VOLTAGE REGULATION CURVES
Of a current regulated generator with vibrator control

control generator charging a battery. At the start this generator gives 18 amperes, but as the battery counter e.m.f. rises it tapers to 5 amperes, with an average of 11.78 amperes per hour. The temperature rise is not excessive, so that this generator is able to handle a battery at 150 ampere-hours capacity or less.

It is to be noted that the voltage regulated generator will not overcharge a battery; therefore, the generator characteristics shown in Fig. 4 are satisfactory for smaller batteries than 150 ampere-hours. However, the generator would be needlessly large for small battery installations—60, 80 and 90 ampere-hour batteries.

The Condition Imposed on the Generator by the Lamp Load—The lamp load and voltage at the lamps must also be considered when choosing a generator. The generator should be capable of carrying the ordinary touring lamp load of side and tail light at a car speed of

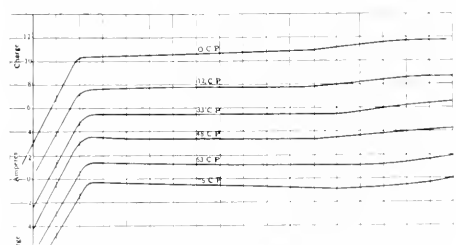

FIG. 8—BATTERY PERFORMANCE CURVES
With a current-controlled generator with vibrator control.

not over 15 miles per hour, and it should be able to carry the entire lamp load of head, tail, dash, tonneau and interior lights and ignition at not over 20 miles per hour. This should be done and a good margin of charging current put into the battery besides at speeds above those stated. Regulation of the constant current type is usu-

ally obtained by a compound winding, so that with the lamp load on the excitation of the generator is increased, and hence its output for a given speed. The curves shown in Fig. 5 illustrate this. These are made with the same generator which produced the results shown in Fig. 3. Since the output of the constant current generator is independent of the battery voltage, it is possible to get very high voltages at the lamps. Fig. 6 shows the voltage at the switch bus, corresponding to the various speeds and lamp loads shown in Fig. 5, with a fully charged gassing battery. The actual voltage at the lamps is about one-half a volt less, due to line drop. From Fig. 6 it will be seen that the voltage of the lamps varies over a wide range, and consequently the brilliancy of the lamp varies. This is a general criticism of this type of regulation. Its great advantages are:—

1—It can break down the sulphate in a battery which has become badly sulphated and bring it rapidly back to a healthy condition.

2—It is simple in the extreme and, therefore, very reliable.

3—With a reasonable amount of battery care, and the use of lamps having six to eight volt filaments (or correspondingly higher for 12 volts), it gives no trouble.

Figs. 7 and 8 show current regulation on a shunt generator by means of a vibrator regulator. With this type of regulation the voltage at the lamps is held within much closer limits, but there is no compounding effect on the generator, and its net output does not increase as the lamp load is put on. Allowing for one-half volt drop in the line to the lamps, this generator would give very poor lamp voltage on heavy lamp loads. Actually

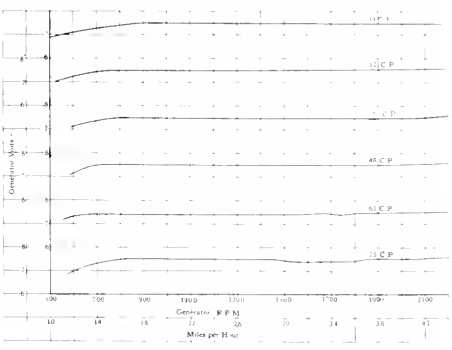

FIG. 9—VOLTAGE REGULATION CURVES
Of a voltage-controlled generator.

it is not able to keep a battery charged under ordinary service conditions where much night running is required, although its rating is practically the same as the generator previously discussed. With current regulation a compromise must be arrived at between generator and battery capacity. It must be remembered that a battery can rarely be injured from charging except by heating, so that to use a generator of large capacity, capable of carrying slightly more output than the full lamp load requires, is safe practice. Voltage regulation is rapidly becoming popular. It vastly simplifies the lighting situation.

1—The voltage at the lamps can be held within very close limits.

2—Current can be put back in the battery at very high rate without excessive voltage or electrolysis of the water in the battery, and hence frequent refilling.

3—The lights may be used from the generator alone if the storage battery is disconnected.

Figs. 9 and 10 show the generator characteristics of the same machine which produced the results in Fig. 4. The "no load" amperage has dropped from 18 amperes to between 7 and 8 amperes, because the battery has been charged, yet it "builds up" its *output* sufficiently to carry a 75 candle-power load (11 amperes). The voltage regulation is so close that the voltage curves had to

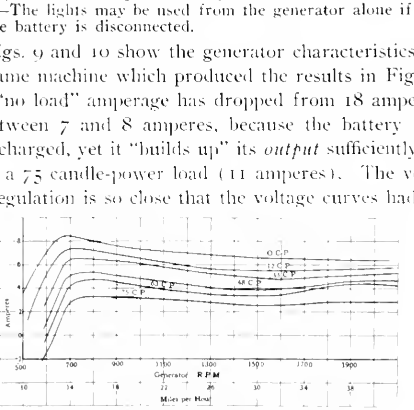

FIG. 10 BATTERY PERFORMANCE CURVES
With a voltage-regulated generator.

be plotted separately, as shown in Fig. 9. It is quite apparent that with this type of regulation the car manufacturer has only to consider whether or not he has capacity enough to carry his lamp loads and charge the battery. He cannot err if he uses a generator of large capacity, a thing he might do with a "current-regulated machine."

There is another point in favor of voltage regulation, namely, that it permits the use of "gas filled" lamps, which give a whiter light and are more efficient than the vacuum lamps. These lamps require close voltage regulation, so that they cannot be used with a current-regulated generator.

The most widely accepted method of securing voltage regulation is by a vibrator which shunts resistance in and out of a shunt field winding. They are fairly reliable, but nearly all are susceptible to pitting of vibrator contacts. The vibrators are delicate and prone to mechanical troubles, but there is no doubt that this method will ultimately be developed to a high state of perfection. One thing a voltage-regulated generator will not do quite as well as a current-regulated generator, and that is "bring back" a sulphated battery. The high internal resistance of the battery holds down the output of the generator.

THE EFFECT OF THE STARTING CURRENT ON GENERATOR CHARACTERISTICS

The preceding discussion on selecting a generator of suitable capacity shows that even in event of the starting motor draining the battery almost entirely, owing to some difficulty with carburetor, ignition or cold weather conditions, the generator, if of proper capacity, would charge the battery in a single day's sustained run, or in a period of several days' short runs. But a series of tests and observations show that under extreme conditions a motor will start in much less than five minutes' crank-

ing, especially if primed. Assuming this to be the case, the generator will recharge the battery in a very short time. Take, for example, our specific case of a six-cylinder, $4\frac{1}{2}$ by $5\frac{1}{2}$ inch engine. It takes 125 amperes to crank this motor at a steady speed of 115 r.p.m. This is a drain of $(5 \times 125) \div 60 = 10.42$ ampere-hours. The generator, if of the constant-current type and of the characteristics shown in Fig. 3, would at twenty miles per hour be charging at 10.56 amperes or better; hence it would, at a charging efficiency of 90 percent, put back the charge in 1.1 hours or less. This is an extreme condition.

The voltage control generator illustrated in Fig. 4 would commence charging at 18 amperes, and taper to about five when the battery came up to charge, giving a mean output of 11.5 amperes and, at 90 percent charging efficiency, it would put back the charge in 1.04 hours or less. This merely goes to show that, given a generator of reasonable capacity, the starting current required is not an important factor and can be neglected.

WIRING

It is particularly important that the car wiring be of extra high grade and installed in a permanent manner.

First—Use wire of ample flexibility, so that vibration will not break it.

Second—Use wire of sufficient carrying capacity to secure good voltage at the lamps.

Third—Use wire having a good grade of insulation, and then carry it in conduits well supported everywhere.

In general, the electrical fittings used on cars are about the poorest things on the whole car. Manufacturers are prone to regard these as unimportant details. Actually they cause more trouble than any other details of the electrical equipment. The insulation of these fittings should be mechanically strong. It should be able to stand up under the application of hot solder without getting soft, cracking or charring. Bakelite, condensite, porcelain and, in general, heat-resisting moulded materials are suitable. Rubber is not desirable in these fittings. Where spring plungers are used in the fittings, the current should have a path around the spring—not through it. Special fittings and plugs should be avoided. Fuses should be used in every circuit except the starting circuit, and they should be of a size that can be found in any supply store.

The merits of the grounded return system of wiring as against the ungrounded returns system the writer does not wish to enlarge upon, except to say that the grounded system is regarded by the majority of car manufacturers as the better of the two,—

First—Because of its simplicity.

Second—Because the fittings are better and less costly.

Third—The saving in copper is considerable and the wiring can be well done even with this saving.

The switches and other electrical fittings should be of sturdy construction. The car manufacturer should keep in mind the fact that all electrical difficulties, from a short-circuit in the wiring to a failure of the battery separators, is usually blamed on the makers of the starting motor and lighting generator. This is a peculiar injustice of the public, but very common. It is, therefore, cheaper in the end to make the wiring of the car and its attendant details a matter of study, and to carry out these details as thoroughly as possible.

The Field for Mechanical Rectifiers

A. L. Atherton

The introduction of the storage battery in lighting systems, as part of the standard equipment of gasoline automobiles before the electrical equipment idea was generally extended to cover charging generators driven by the engine, created a demand for an inexpensive form of apparatus to charge these batteries from ordinary lighting circuits. Owners of cars not equipped with charging generators found it expensive to depend upon the public garage to keep their batteries charged, and those who kept their machines in private garages had an added incentive to the use of some home charging device in the inconvenience of getting their batteries to and from the public garage for charging.

This led to the development of various forms of mechanical rectifiers, one of which is shown in Fig. 1, which, by use of transformers, reduce the voltage of the lighting circuit to the proper value, and by means of electrically-operated switching mechanisms rectify this reduced voltage to unidirectional voltage suitable for battery charging. In the outfit illustrated in Fig. 1, the circuits of which are shown on Fig. 2, the transformer serves the double purpose of reducing the line voltage to the proper value for the battery to be charged and of providing a neutral, or return path, for the direct current. The load current flows from one end of the secondary winding, through the regulating resistance, through one pair of contacts which are automatically closed at the proper time and out from the center point of the armature to the battery, from which it returns to the central point, or neutral, of the transformer. During the succeeding half cycle, when the voltage of the transformer secondary is reversed in direction, the other pair of contacts is closed and voltage is applied to the battery from the half of the secondary previously idle, this voltage being in the same direction as on the previous half cycle. The current delivered to the battery is thus unidirectional and charges the battery exactly as if direct current from a generator were supplied.

While the transformer performs a valuable service in reducing the line voltage to the required value without direct loss, and in thus maintaining a comparatively high

efficiency, the element on which the success of the outfit is based is the vibrating mechanism. It is the duty of this part of the apparatus to reverse connections in synchronism with the voltage and also exactly in step with the secondary voltage in such manner as to open the current carrying circuit at the instant of zero current and thus prevent sparking and injurious wear of the contacts.

Two small laminated iron magnets, marked *A.C.* magnets in Fig. 2, are connected in series across one-half of the transformer secondary, connections being made so that the corresponding ends of the magnet are of the same magnetic polarity. A direct-current magnet, polarized by shunt current from the battery, is so placed as to bring its ends within the effective field areas of the *A.C.* magnets. Since the ends of the *D.C.* magnet are of opposite polarity, they are forced at any instant in opposite directions by the fields of the *A.C.* magnets and one pair of contacts is closed. During the succeeding half cycle the *A.C.* magnets are reversed in polarity, while the *D.C.* magnet is not, the impelling force is reversed, and the armature takes such a position as to close the other pair of contacts. One side of the battery is thus connected alternately to the opposite ends of the secondary of the transformer in synchronism with the alternating voltage, while the other side is permanently connected to the center point. Exact timing to insure sparkless operation, by breaking the current carrying circuit at the time when the battery and transformer voltages are equal and opposite and no current is flowing, is secured by connecting in series with the *A.C.* magnets, a resistance which alters the power-factor of the current in the magnets without affecting that of the load current in the transformer. This change in power-factor translates in time the impelling force, with respect to the current in the contacts, and secures the result of sparkless operation. This phase-controlling resistance is made variable, in order that the outfit will be applicable on circuits of which the wave form is not a true sine wave, and on circuits on which the voltage is not of normal value. The condensers connected around the contacts reduce to a negligible amount the unavoidable slight sparking, due to fluctuations in the line voltage, variation in wave form and change in battery voltage. The regulating resistance, which is connected in each side of the secondary circuit between the transformer and the stationary contact, is for the purpose of giving the outfit high or poor regulation, in order that the change in battery voltage, as the charge progresses, will make only a small change in the current delivered. The standardization of lighting batteries in general use has resulted in the selection for the commercial form of this apparatus of such transformer voltage and resistance value as to make the charging current under normal conditions approximately 8.5 amperes at the start of charge and 6.5 amperes at the finish.

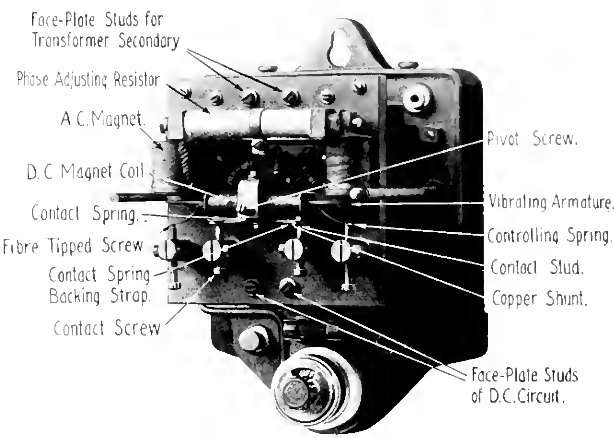

FIG. 1—WESTINGHOUSE VIBRATING RECTIFIER
With cover removed, showing mechanism complete.

The features above mentioned result in an outfit which can be connected to an ordinary alternating-current lighting circuit and to a battery, without attention to polarity, owing to the polarization of the *D.C.* magnet by the battery, and which will then, after a single adjustment of the phase-controlling resistance, give a full charge to the ordinary lighting battery without further attention. The cost of power for such a charge at the common rate of 10 cents per kw-hr. is roughly 6.5 cents, as compared to the ordinary charge of 75 cents to $1.25 per charge by a public garage.

At first sight, it would seem that the present almost universal use of charging generators would completely destroy the usefulness of this form of apparatus, since these rectifiers are primarily for use in charging single batteries. A more careful survey of the situation, however, reveals the fact that there still remains a considerable field for these devices. In the first place, there are still in use a large number of machines not equipped with electric lights, which can be wired for lights and supplied with a battery at small cost, but for which a generator is prohibitively expensive. There are also machines equipped with lights to operate from the magneto, or from a battery already installed, but with which there is no generator equipment. Lighting from a magneto is unsatisfactory in some cases, and a battery may be cheaply installed, while a generator is comparatively expensive. In these cases the mechanical rectifier fills a real need by decreasing the investment required to modernize an old car, or to add almost necessary conveniences to one incompletely equipped. This field of usefulness, while great now, is, however, unquestionably decreasing and will eventually become of small com-

mercial importance. The permanent field, or that which grows with the industry, has for its origin the natural limitations to the commercial form of charging generators.

No automatically regulated charging system can be made to keep a battery charged under all conditions of use. The load on the battery varies with the amount of evening use, when the lights are burned, and with the frequency of starting the engine. The input to the battery from the charging generator varies with the amount of running of the car or truck and with the engine speed. Where the car is used mostly in the daytime and is frequently in use, the battery will normally stay charged. When a car is used mostly at night and is occasionally left standing with some lights burning, the battery will tend to discharge and will fail to build up its charge again, and an occasional charge from an external source is necessary. Further, all lead batteries require frequent overcharges to prevent decrease of capacity due to incomplete conversion of active material by the normal charge. Storage battery manufacturers are beginning to recommend an occasional extra charge for all lighting and starting batteries regardless of the class of service and type of charging equipment.

The infrequent but necessary charges mentioned in the foregoing, which applies to pleasure vehicles and trucks in ordinary service, are furnished conveniently, simply and economically by means of the mechancial rectifier. There are, morover, certain special cases in which the extraordinary features of service conditions eliminate all possibility of satisfactory charging of the batteries by engine-driven generators. The special features of service which are present in these cases, and which prevent satisfactory charging by the electrical equipment on the car, are merely exaggerations of the points mentioned above, viz., infrequent use and heavy battery drain during use. As examples of this class of service, we may consider some special cases of service in which these features are most pronounced.

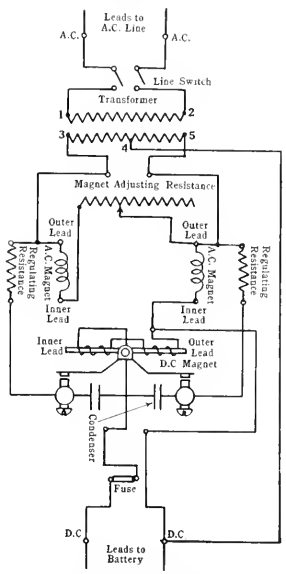

FIG. 2—DIAGRAM OF CONNECTIONS OF RECTIFIER SHOWN IN FIG. 1

Most fire department regulations require a periodic inspection of gasoline engine-driven equipment, to insure its availability for instant service, and this inspection includes a trial of the starting motor once or twice a day. Starting is usually repeated several times at each trial, so that there are from two to ten starts made per day with this equipment, which makes no inconsiderable drain on the battery. On the other hand, the service which the truck performs is such as to afford little, if any, opportunity for charging from an engine-driven generator, for, though the speed is high and fairly constant, the runs are short and infrequent, and many times, on night runs, the powerful lights are all in use and are making a further heavy drain on the battery. For this service it is hopeless to attempt to keep a battery in condition by means of the normal equipment of a generator driven by the engine, and the only solution is the use of a separate charging equipment and preferably, owing to the prohibition of all delays, two batteries—one of which is kept in the machine, charged and ready for immediate use at all times.

Another and somewhat different example of unusual service is the gasoline engine-driven hearse. The service rendered by an undertaker is such as to make the use of the car irregular and, since the battery charge will decrease in periods of idleness, separate charging becomes necessary. In this case, and in other similar ones, there is no necessity of the readiness for instant service, which is a prime requisite in the case of a fire truck, and a single battery charged periodically from an outside source fills the requirements.

The same features of special operation, except applied to cycles of long duration, introduce a further comparatively wide field of application. In the sections of the country where winters are severe, many people store their machines from fall to spring in preference to paying the higher operating and upkeep expenses and risking frozen radiators. Lead storage batteries, unless taken apart and stored and reassembled in the spring, must be cared for during this period of inactivity by occasional charging. While this service can be secured from garages, many prefer to do this work at home, especially as the same investment makes them more independent of public garages during the months of active service of the car.

Assuming the ordinary touring car, roadster or truck to be the normal machine for which, when normally operated, all requirements of charging are filled by a charging generator driven from the engine, the extreme case of special service is exemplified by a fire truck to suit the requirements of which it is quite impossible to furnish an accessory generator. Between these two extremes are many classes of service, the special features of which vary in degree. Upon this degree of variation from normal depends the frequency with which charging from an outside source is necessary, and upon this frequency, together with other conditions such as the cost and convenience of buying these charges from a public garage, depends the demand for the mechanical rectifier.

Electric Passenger Cars

Gail Reed
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THE ORIGIN of the battery vehicle dates back many years, but the first developments of the electric passenger car on which information to any extent is available dates from the year 1892. The first cars were crudely constructed and represented merely experimental steps, with little attempt to gain efficiency or silent operation. This initial experimental stage continued to the year 1898, when several foresighted engineers undertook the developing of passenger vehicles on a commercial basis.

THE first electric passenger cars can be described best as a combination of carriage building with street car construction. The rear axle had the wheels solidily fixed to it, and revolving as a whole. The motor was suspended from and geared to this revolving axle. A combination of this construction was brought out in several models, first, in a light runabout using a revolving axle with the motor suspended and geared the same as on street car construction, and later, a combination of this construction, viz., a solid rear axle with two motors bolted on, with one geared to each rear wheel. This construction proved very efficient, but as time went on it was found necessary to greatly strengthen the different parts in order to afford the required stand-up qualities under service. It was impossible, however, to gain silent operation from this construction.

On January 1, 1900, an automobile parade was held in Cleveland, Ohio, which was probably the first parade in automobile history in which electric passanger cars took part. The day was very cold, and on that account the Locomobile steamer and the Winton experienced considerable trouble, while the electrics gave a beautiful exhibition. Thus the initial public performance of the electric vehicle clearly demonstrated a most important characteristic which has always remained the electric's very own—dependability.

In 1904 the early chain drive models appeared—one make having a runabout body equipped with a single chain drive to a revolving rear axle operated on pneumatic tires. Another manufacturer brought out a double side chain driven car operating on solid tires. The engineer responsible for the side chain driven car also brought out at this time a shaft drive car, which was, so far as is known, the first electric shaft drive car. This model was constructed with a slow-speed motor, connected through a double universal jointed propeller shaft to the rear axle, without chain or gear reduction, except the ordinary bevel gear reduction in the rear axle. The principles of this first shaft drive model laid down 15 years ago formed the basis of construction that is generally acknowledged today as the foremost standard of construction in the modern electric passenger car.

The success of these cars was by this time attracting others to the commercial possibilities of the electric vehicle, and several additional concerns took up the manufacture of passenger vehicles. The battery equipment varied from 10 to 40 cells and chain drive was used, with the exception of the one model already mentioned. Nearly all cars were built to use pneumatic tires and small batteries. From this period on to 1908 many experimental stages were passed through, the cars being turned out in moderate quantities and operating with considerable success.

In 1908 and 1909 the industry made its greatest gains. The chain drive construction gave way to the shaft drive, with its attendant simplicity and silence. During the experimental years the vehicle manufacturers were not alone in working out their problems, but the many allied interests were giving their full quota of time and study to the development work; particularly was this true of the manufacturers of motors, batteries, tires, bodies and electrical equipment.

In 1910 and 1911 the manufacturers of electric passenger cars first came to realize the advantages to be gained through co-operation with these same experts—the parts specialists—not only with respect to production facilities, but particularly from the standpoint of efficient standardization. The demand had outgrown the facilities and, in spite of the rapid increase in the business as a whole, no material gain had been made in raising the manufacturing efficiency or in commensurately lowering production costs. For that reason the prices on electric passenger cars remained where they started, while the manufacturers of gas cars were making tremendous strides through proper factory organization and parts specialists construction—both factors leading toward reasonable standardization and a consequent lowering of prices.

By 1912 the electric passenger car manufacturers were forced to admit that, in order to keep up the pace, it would be imperative that they standardize and take into full consideration the manufacturing methods already adopted by their gas car brethren. The following demands had crystallized from their previous efforts:—First, the demand for solid rubber tires (the use of which was confined exclusively to the electric on account of its structural simplicity), which one engineer

had used for 12 years. He proved conclusively that it was feasible and practical to operate the electric vehicle on solid tires provided the proper construction was used. The next demand was for a greater radius of action and increased speed. This brought the leading manufacturers, who had used from 20 to 24, 28, 36 and 38 cell equipments, to a general use of not less than 40 cells. Another demand was body construction affording greater passenger capacity, which brought out the wide rear seats, affording ample room for three persons, with extra revolving seats for two additional passengers. The fourth major demand was a control equipment that simplified the operation of the car and provided safeguards against improper handling. The steps employed in perfecting the vehicles to meet these demands, as well as the many additional requirements that have since developed, brings us to the modern construction used in the electric passenger car of today.

PRESENT TYPES OF CONSTRUCTION

The following description of the present electric passenger car construction has been prepared to apply as nearly as possible to the average general construction adopted by the leading manufacturers. The electric passenger vehicle has been, to a large extent, responsible for the high degree of perfection attained in the heat treatment of steel, for it was on electric vehicles that heat-treated steel was first used in automobile construction. This was due primarily to those cars using solid tires, a practice which necessitated the development of better materials throughout in order to withstand and absorb increased vibrations. The general mechanical construction of the cars today employs, to a great extent, the use of heat-treated special formula steel.

CHASSIS FRAME

The steel frame is built up into an extremely rigid unit; with scientific distribution of metal, using an average of from six to eight cross channel reinforcements, integrally gusseted, completing a rigid foundation of extreme strength, particularly adapted to the use of solid rubber tires. The frames are now being constructed to make it unnecessary to lift the batteries over obstructing end channels in removing, and the front ends are narrowed to permit an extremely short turning radius.

AXLES

Practically all cars now use the I-beam type of front axle and a one-piece steel housing type of rear axle.

BEARINGS

Timken roller bearings are being favored as the proper bearing mountings for axles and wheels. S.K.F. self-aligning ball bearings are fast gaining favor for use in the steering parts.

MOTOR

The slow-speed type of motor has been adopted by the majority of manufacturers. In general, this motor conforms to the following specifications:—800 to 900 r.p.m. at 80 volts and 28 amperes, 4 pole series type, unsaturated, generally designed so the frame will take two windings—60 or 80 volts—to be used principally with 60 cell Edison or 40 cell lead batteries, respectively. These windings are proportioned so they deliver equal horsepower at their respective ratings; in other words, the two windings are proportioned so that they have equal watt ratings at the same torque and the same speed. This construction facilitates the changing of the motor from one type of battery to the other without change in the motor suspension or mechanical transmission system.

The motors are designed so as to secure strength with a simple arrangement of few parts. Considering the service that is demanded from the modern electric passenger car, it is remarkable how little attention these motors require. While most vehicle motors are periodically inspected, it is known that many have covered from eight months to over a year's continuous service without attention of any sort. Such attention as is necessary is generally confined to renewing of worn brushes and replenishing the bearing lubricant. The motors are proportioned so as to commutate sparklessly and maintain a high polish on the commutator, even when operating under the severe service required in hilly towns or adverse weather and road conditions, where the motors are required to commutate from five to six and even more times the normal rated current.

The majority of manufacturers have found it necessary to install, in general, heavier windings than would be normally required, in order that all hill conditions can be satisfactorily met. The wide-awake manufacturers will meet these requirements more efficiently in the near future by using standard motor frames with different windings to meet the various duties.

The ordinary performance specifications as to temperature runs as follows:—After a continuous run (for four hours) at the specified voltage and current, no part of the windings will exceed a temperature of 50 degrees C. above the surrounding air. Test to be made on stand with motor covers removed. Temperatures are to be measured by thermometer. All motors are mounted on ball bearings. The bearing housings constructed so the lubricant cannot work into the motors and are designed to catch any oil that may work by the barriers. The range of weight of motors in this service runs from 235 to 300 pounds. When full consideration is given the duty these motors are called upon to perform, viz., to drive a vehicle weighing without occupants an average of 3600 to 4000 pounds at a rate of 20 to 22 miles per hour, their extreme high efficiency is remarkable, a characteristic which is especially pronounced when operating under extreme overload.

Operating data taken from a late model electric passenger car is given in Table I. This car had been in continuous service and received no special tuning up. This particular test is one of many similar records that have made equally as favorable a showing. It will be seen that the vehicle motor development brought about by the modern electric passenger car has reached a very

high stage of perfection. Practically all motors are mounted on a substantial sub-frame in the center of the chassis. In this position they are well protected from direct road shocks.

TRANSMISSION

The power is transmitted through a double universal-jointed propeller shaft to the rear axle through one set of worm bevel gears. The worm bevel or spiral bevel gear is given the preference over the worm as standard equipment for the following reasons:—In the first place, practice has proven that it will give considerable higher average efficiency. The recent announcements of several leading manufacturers show that they are adopting this type of gear in preference to the worm. While the characteristics of both gears are practically the same as to silent operation, the higher efficiency of the worm bevel alone is ample reason for its preference, particularly on the electric.

The rear axle is held in alignment by the lower halves of the rear springs, and the torque stress is taken up by a torsion rod, which is fastened permanently to the rear axle, with the exception of being free to move at right angles to the plane of the torque. The front end of this torsion rod is suspended between two coil springs, which serves to remove some of the stress from the rod and to eliminate noise. In order to permit two points of contact on the rear axle and consequent greater strength of leverage the torsion rod is of the "V" shape design.

TABLE I—OPERATING DATA

Speed	Weight		Power			Per Ton-Mile		
Cont'ler speed	Car	Pas.	Volts	Amps	Watts	Watts	Rate	Cost
1st 5 miles.	3675	325	40	8	320	32	5c	$0.0016
2d 8 miles.	3675	325	40	10	400	25	5c	0.00125
3d 12 miles.	3675	325	80	20	1600	66	5c	0.0033
4th 18 miles.	3675	325	80	25	2000	55	5c	0.00275
5th 22 miles	3675	325	80	35	2800	64	5c	0.032

CONTROLLER

The tendency on the majority of electric passenger cars today is to locate the controller as close to the motor as frame construction will permit, thus materially cutting down the length of the wiring and making the controller and motor both accessible from the same inspection door. The five-speed forward and reverse drum-type controller is used by practically all electric vehicle manufacturers. Some engineers prefer to have the batteries connected in series on all speeds, but the series-parallel connection with the elimination of resistance speeds is now the most widely used form. The best practice incorporates a bridging coil between second and third speeds to eliminate the shock and usual arc, due to changing from 40 to 80 volts. The best construction is to use wiring no smaller than No. 4 for the main circuits.

The old practice of using the knife switch for reversing has been discarded for the more general use of the separate, or reversing drum, which may or may not be on the main controller shaft. Although the action of reversing on the controller proper is uniform on all makes of electric vehicles, the method of throwing the reversing drum is essentially different. On the Chicago Electric, the reversing drum is not operated on the main controller shaft, but is independent of the main controller drum and a foot pedal or floor push located near the floor on the heel board is used for throwing this drum. On other makes of electric passenger cars the reverser control is incorporated in the controller handle, on a separate lever, and sometimes even on the brake pedal itself.

There is used in connection with the main controller drum on the Chicago Electric a simple mechanical device that governs the operation of the reversing drum, whose use makes it possible to cut off all power without moving the controller handle and renders it impossible to throw the reverse drum while the car is in motion or while the controller is in speed position. The majority of electric passenger cars incorporate what is termed an electric cut-out in connection with the foot brake, which is generally arranged to operate through the reverse drum in the controller. When the foot brake is set the reverse drum is automatically thrown to a neutral position, thus cutting all connection between the controller and the motor. This safety feature makes it impossible to set the brakes without cutting off the power. Likewise it is impossible to apply power or start the car until the brakes are released.

Several other improvements are now incorporated in the controller proper, viz., a magnetic blow-out to eliminate or take up as much of the arcing as possible and a self-lubricating wipe system for the contacts. All controllers are protected from dirt and dust by metal housings.

OPERATION

With a few exceptions, all electric passenger cars are now operated by the horizontal control lever. Most of the manufacturers are now operating a mechanical or electrical motor brake through this same control lever so that all power is applied, cut off and the brakes operated through the one lever and the entire system secured by a Yale lock upon leaving the car. In addition to the hand brake, all cars are equipped with dependable foot brakes operating on both rear hubs.

A study of the general construction shows that the electric passenger car is making very good progress toward standardization. Outside of minor refinements, the general construction of all leading makes have remained basically the same for the past three years. The engineering has been devoted to improved efficiency throughout, increased accessibility of all parts and better lubrication.

MAINTENANCE DATA

The data on actual operating costs given in Table II has been carefully compiled by a leading manufacturer. The figures are not based on ideal cases, but give as fair a general average as can be compiled on the total main-

tenance of the electric passenger car of today. The following notes will serve as a guide on the basis for many of the figures given:—

Insurance—Includes full coverage on public personal injury, property damage, damage to car, fire and theft.

Tires—Figured on basis of using Firestone Special Electric, 36 by 4½ inches, guaranteed for 10 000 miles.

Paint—Complete burn-off.

Overhaul—Figures obtained from service records, where all work is done on cars.

Garage—Thirty-five dollars per month, which covers charging, washing, polishing, deliveries and storage.

Batteries—Complete renewal, carrying guarantee of 12 000 miles. Including wash job and incidental repairs. On rental batteries, charge of $16 per month.

TABLE II—MAINTENANCE OF ELECTRIC CARS

WHEN KEPT IN A PUBLIC GARAGE
Based on 12 000 Miles Per Year.

	Electric	Extra Cost of Gas Car
Insurance $2000.00	$ 135.00	11
Tires	250.32	100
Paint	125.00	20
Garage	420.00	−29*
Overhaul, etc.	75.00	366
Batteries and battery incidentals	350.00	
Total	$1355.32	27
WITH RENTAL BATTERIES		
Batteries	$ 192.00	37
	$1197.32	44

WHEN KEPT IN PRIVATE GARAGE

While no allowance has been made for cost of space or rent, and such items as flushing, washing and polishing, it is only fair to state that these items should be considered under private garage, for all these items are included in cost under public garage.

	Electric	Extra Cost of Gas Car
Insurance $2000.00	$ 135.00	11
Tires	250.32	100
Paint	125.00	20
Overhaul, etc	75.00	366
Batteries	350.00	...
Current	144.00	...
Total	$1079.32	32
WITH RENTAL BATTERIES		
Battery	$ 192.00	...
Total (Current based on flat rate of 0.055 per kw-hr.)	$921.32	55
WHEN KEPT IN A PRIVATE GARAGE Based on 6000 Miles Per Year.		
Total	$669.66	29

*Difference in favor of gas car. This includes the cost of charging the electric car, but does not cover gasoline or oil for the gas car.

NOTE:—For those who want comparative percentages of gas cars with electrics, a column entitled "Saving in percent over gas cars" has been added. The figures upon which the gas car percentages are figured were obtained from various repair shops, garages and private owners and represent a fair general average. As in the case of the data on electrics, liberal allowances have been made, as, for example, on paint, where figures are based not on an ordinary revarnish or $75 paint job, but on the best job procurable, viz., a complete burn-off.

Inasmuch as a chauffeur is necessary with the majority of gas cars to give the same full service as an electric, the following figures apply. Both cars kept in public garage and gas car run by chauffeur, using same figures as before on other items.

		Extra Cost of Gas Car
Total upkeep for electric	$1355.32	116
WITH RENTAL BATTERY.		
Total upkeep	1197.32	144

Both cars kept in private garage and gas car run by chauffeur:—

Total upkeep	$1079.32	143
WITH RENTAL BATTERY.		
Total upkeep	921.32	185

TABLE III—COST OF OPERATING ELECTRIC CAR ON COST-PER-MILE BASIS

Garage-Private. Battery Bought.	6000 Miles per annum	12 000 Miles per annum
Tires	$0.02086	$0.02086
Overhaul, etc	0.00625	0.00625
Batteries	0.0291	0.0291
Current	0.012	0.012
Total	$0.06821	$0.06821
With Rental Battery	$0.032	$0.016
Total	$0.07111	$0.05511
Garage-Public. Battery-Bought	$0.0291	$0.0291
Total	$0.12621	$0.09121
With Rental Battery	$0.032	$0.016
Total	$0.12911	$0.07811

LEAD BATTERIES

The standard lead battery equipment is 42 cells of 11, 13 or 15 high-capacity plates per cell. The tendency seems to favor the use of thinner plates and more of them; 15 plates are furnished as standard more frequently than any lesser number. This equipment will give 180 ampere-hours, and in most cases develops a full 200. There are two reasons for the adoption of the thin-plate lead battery:—1,—the growing demand for increased speed and mileage; 2,—the discovery on the manufacturers' part that the life of the thin-plate battery is equal in every respect to that of the heavier plates. One standard size of jar is now being used that will take from 11 to 15 plates. The high-ribbed type of jar is used, having at least a three-inch sediment space, which eliminates frequent battery washing. The assembly of jars in trays is side to side with a single row per tray, with the surface of the plates set at right angles to the direction of motion and the trays set in the battery compartments lengthwise. This arrangement is favored on account of its compactness and accessibility and reduction of jar breakages.

Much credit is due the standardization committee of the Electric Vehicle Association of America, especially the committee on standards of the Chicago Section, for the excellent work that has been done toward battery standardization. While the lead battery as a whole still remains in a rather unsatisfactory position with regard

to standards, a very good start has been made in the right direction. The car manufacturers realize the importance of reducing the multiplicity of battery specifications and will keep fully in mind the proper modifications necessary on all future designs to bringing about a reasonable and efficient battery standard.

Battery standardization leads to one of the most important of recent electric vehicle developments. A move that promises great possiblities toward expanding the range and use of electric vehicles, viz., "The Battery Service System" or "Battery Rental System." While this development is not altogether new, more attention has been given its operation in the last three months than ever before. Several plans, differing in many details but similar in principle, have been placed in active operation in different parts of the country. So far but one passenger car manufacturer has openly espoused the battery service system, and in this case it is restricted to the Chicago territory proper, the other battery service systems being confined to commercial electric cars. This battery service plan is in brief as follows:—The electric vehicle is sold originally without battery, the battery cost being deducted from the original selling price. The purchaser contracts for the battery service, which covers the proper capacity battery, at a stipulated monthly cost. This flat rate covers all maintenance and repairs and guarantees at all times 80 percent of the battery's full rated capacity when properly charged. If repairing is necessary a new battery is installed. Two months out of each year is allowed for such time as the car may be taken out of service, for which period no charge is made. The car owner assumes all responsibility for fire, theft and accident. For example, a 40 cell, 11 plate battery is furnished for $16 per month. A payment of $25 additional is required the first month if no old battery is turned in. This gives a total of $217 for first year, if in service the full twelve months. If out of service two months, which is customary with most cars, due to vacations or other reasons, $32 is deducted from the total, leaving $185 for the first year's full service. Thereafter annual service would cost $192 for twelve months, or $160 after deducting the usual two months out of service. A service of this nature assures a fixed low battery maintenance; a lower initial investment; continual maximum capacity, which will increase the range of action very materially; minimum loss from delays, and an important reduction in charging losses due to the battery being in most efficient condition at all times. The manufacturer who inaugurated this system in Chicago claims a very material increase in sales and a lively interest on the buying public's part in such a service.

That a battery service system on similar lines can be established for general use is entirely feasible and practical. When that time arrives the electric vehicle will really come into its own, but before such a system can be extended on any but a very limited scale it will be necessary for the manufacturers to standardize the battery compartments, distribution of cells, and jar sizes.

EDISON BATTERIES

Recent developments in the Edison alkaline storage battery hold forth great possibilities for the electric passenger car. Edison batteries have developed a great field among the electric commercial cars, their installations for this work showing a very pronounced increase. The electric passenger car requirements differ in some respects, and to best meet these demands the new "G" type of Edison cell has been recently developed for electric passenger car service. The standard Edison equipment is 60 "G-7" type cells, which gives a normal rating of 175 ampere-hours and develops an average of 2.25. In addition to the general advantages of the Edison cell, the following improvements are offered in the new "G" type cell:—The internal resistance has been cut down approximately 50 percent. For that reason the "G" type is considerably less affected by temperature changes, in addition to permitting a considerable lower average rate of charge.

SUMMARY

A review and analysis of the late electric passenger car clearly indicates that the experimental stage is long past; the old carriage idea, the woman's toy., etc., has grown into a scientifically designed electrical and mechanical masterpiece. The most careful attention that modern engineering science can give has developed a car that meets most completely all the requirements of the finest motor car, with greatest economy, efficiency and comfort.

Safety is synonymous with the electric car, and ingenious engineering has developed the safety factor on the modern electric to the highest degree. The electric car has won first position in the public's esteem for ultra refinement, serviceability and economy. Approximately thirty-five thousand electric passenger cars are operated in the United States today.

Haphazard manufacturing methods have disappeared before highly efficient, specialized production. Standardization and specialization have been responsible for the reduction in price, averaging nearly 25 percent in the past two years. At the same time the quality of the cars in design, material, workmanship and refinements has risen at least a like percentage.

It is most reasonable to assume that this combination of important factors will bring a much more rapid expansion in the electric car industry which should double the number of electric passenger cars in operation in the next five years.

Operating Characteristics of Lead Acid Storage Batteries

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TO THE USER of lead acid storage batteries in self-propelled vehicles, the steady improvement of recent years is hardly noticeable to the eye, although there has been an increase in the watt-hour capacity of the battery per unit of space and weight, and also in the serviceable life of the battery. There has also been a marked advance in the permissible rates of charge and discharge, which has added so much to the flexibility of operation as to permit the use of much smaller batteries than would have been considered a few years ago in the same service. The following article explains the permissible rates of discharge and the behavior of batteries under operating conditions which a few years ago were considered prohibitive.

IT CAN be safely said that high rates of discharge are in no way detrimental to modern lead battery plates. Batteries of the vehicle type are in regular operation under conditions in which practically all their work is done at rates which would empty the battery in ten minutes, and the same batteries would be sold to operate at the three-minute rate if there were a commercial demand for such operation. For such high rates of discharge, extra heavy terminals are provided to carry the current, no other changes being required.

It is well known that when discharged *continuously* at a constant rate, the available ampere-hour capacity of a battery is a function of the rate of discharge, the available capacity being lower at the higher rates. This reduction in available capacity at the higher rates of discharge is due to depletion of the acid in the pores of the plates. The rate of this depletion is the difference between the rate of absorption by the plates of the acid that is in the pores of the plates, and the rate at which this acid is renewed by diffusion with the other acid in the cell. It is the limit of this available acid that limits the capacity of the battery at high rates of discharge, and not any limitation in the plates themselves. It is, therefore, impossible to damage the plates by overdischarge at high discharge rates. In fact, very low rates of discharge should receive more careful consideration than very high rates.

The variation in available capacity of a well-known battery when discharged continuously at constant rates is shown in Fig. 1; also the initial, average and final voltage per cell under the same conditions. This curve is drawn on the basis of the battery giving its rated capacity in 4.5 hours. If a battery be discharged intermittently, it is evident that during periods of rest the acid in the pores of the plates is being renewed by diffusion with the other acid in the cell. It follows that the reduction in available capacity, due to high rates, largely disappears when the high rate are intermittent. If the total elapsed time during which discharges are made be greater than 4.5 hours and if the high rate discharges are approximately evenly distributed throughout the time, so that there will be time for this diffusion to take place, approximately the full capacity of the battery will be available.

The curves in Fig. 2 are the result of tests and show the voltage and ampere-hours of discharge of a cell when discharged continuously at the nominal five-hour rate (25.8 amperes); also of the same cell when discharged in cycles of four minutes at five times this rate (120 amperes) with 17 minute rests, and also when discharged in cycles of two minutes at ten times this rate (258 amperes) with 19 minute rests. This battery was somewhat above rated capacity and gave 157 ampere hours at the nominal five-hour rate in six hours and four minutes. On intermittent discharge at five times the five-hour rate it gave 146.2 ampere-hours in five hours and 40 minutes, and at ten times the five-hour rate it gave 137.6 ampere-hours in five hours and 17

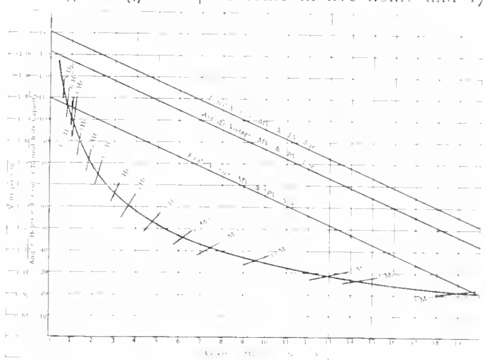

Fig. 1—PERCENT VARIATION IN CAPACITY
With change in rate at high rates of discharge of an Ironclad Exide battery

minutes. The voltages shown throughout these discharges are amply high to meet the requirements of thoroughly good service.

Another illustration of the way advantage may be taken of the effect of acid diffusion may be shown by reference to a submarine boat. Suppose a battery is used of sufficient capacity to drive the boat submerged at full speed for one hour, and suppose this takes 3000 amperes, after a one-hour run the battery will be practically empty at this rate, and its voltage will begin to fall rapidly if discharge at this rate is continued. If, however, the speed of the boat is now reduced so that the discharge will be reduced to say 1350 amperes,

which would drive the boat at approximately half speed, the rate of acid absorption by the plates will be reduced to less than one-half its former value, but the rate of diffusion will not be changed, more acid will become available in the pores of the plates and the discharge may be continued for some time before the available acid is again used up. Successive reductions in the rates of discharge could be made and submerged operation of the boat continued at correspondingly reduced speeds. The curves in Fig. 3 are the result of a test on a submarine type cell discharged in this manner. While the capacity of this cell was 3000 amperes for one hour, it is shown that an additional 3000 ampere-hours of discharge was obtained at serviceable rates and at serviceable voltages, thus doubling the radius of submerged action without overdischarging the battery or damaging it in any way.

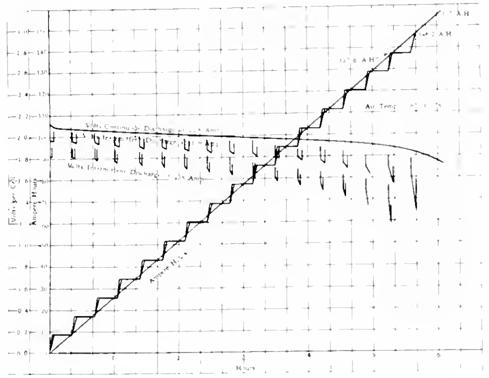

FIG. 2—INTERMITTENT DISCHARGE CAPACITY

At high rates of an MV-9 Ironclad Exide battery compared to normal discharge.

Discharge at 25.8 Amp.—Average Volts 1.973 Temp.—Start 94 deg.—Finish 87 deg.
Discharge at 120 Amp.—Average Volts 1.807 Temp.—Start 99 deg.—Finish 100 deg.
Discharge at 258 Amp.—Average Volts 1.633 Temp.—Start 97 deg.—Finish 109 deg.
Capacity when discharged continuously at five-hour rate (25.8 amp.) 157 ampere-hours.
Capacity when discharged in cycles of four minutes at five times five-hour rate (129 amperes) with 17 minute rests 146.2 ampere-hours.
Capacity when discharged in cycles of two minute at ten times five-hour rate (258 amperes) with 19 minute rests 137.6 ampere-hours.

CONTINUOUS DISCHARGE RATED CAPACITY

25.8 amperes 5 hours—120 ampere-hours.
120 amperes 32 minutes — 69 ampere-hours.
258 amperes 11 minutes — 47 ampere-hours.

It will be noted that the voltages shown in this test are lower than those shown at corresponding rates on the curve in Fig. 1. The use of larger plates in the submarine type of cell necessarily introduces more IR drop in the plates, which accounts for this difference. Taking advantage of these characteristics has added materially to the use that can be made of a battery where space or weight conditions are limited, or if the work to be done is fixed they permit the use of smaller and correspondingly cheaper batteries.

Equally important advances have been made in permissible charging conditions, with the result that the best rates to use in charging a battery are now generally determined by the particular local conditions under which the battery is operated rather than by limiting conditions imposed by the battery itself. In the early days of the vehicle battery, the life of the battery was considered in terms of the number of charges, and a charge once started was supposed to be completed before the battery was again used. The charge was started at a certain rate determined by the size of the battery, and continued until the cells began to gas, when the rate was reduced to about 40 percent of this value, and continued until the cells again gassed freely. Later a certain amount of "boosting" was permitted, the term "boosting" being used for partial charging given in a comparatively short time and usually at rates higher than were permitted for regular charging. It is no longer necessary to differentiate between these two forms of charging.

In general, a battery may be charged at any time when a charge will be useful and at any rate which will not cause the temperature of the battery to exceed 110 degrees F. and which will not cause the cells to gas freely except at low rates of charge. If these conditions can be watched no further directions or limitations need be considered. As it is not always possible to watch these conditions, several methods of charging have been worked out which reduce the amount of attendance required while charging, and which permit the selection of the most economical way to charge the battery under any particular set of local conditions, while assuring that the above limitations will not be exceeded.

A general rule for determining the maximum permissible rate of charging a battery is:—The charging rate in amperes must never exceed the ampere-hours out of the battery. Any method of charging that keeps the charging current within this limit will not overheat the battery or cause it to gas. In applying this rule it is not necessary to reduce the charging rate below the "finishing" rate recommended by the battery manufacturers. If an ampere-hour meter is used on the vehicle, so arranged as to indicate the ampere-hours *out* of the battery, it also indicates at all times the maximum permissible charging rate. It will be noted that the maximum charging rates are no longer a function of the size of the battery or its relative state of discharge, but depend only on the actual state of discharge. The curve in Fig. 4 shows in percentage the theoretical variation in charging rate and also in state of charge if a battery were charged strictly in accordance with this rule, and this represents the method by which a battery may be safely charged in a minimum time in regular operation.

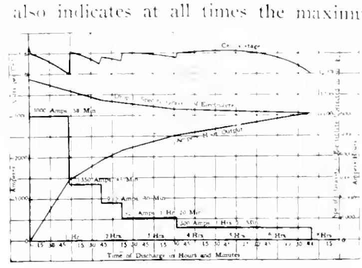

FIG. 3—DISCHARGE CHARACTERISTICS

Of 29-U Exide cell at varying rates

The curves in Fig. 5 are the result of test and show the charging rate, the state of charge, cell voltage and temperature of a battery when the current was adjusted each minute in accordance with the above rule until the recommended finishing rate is reached. It will be noted that the temperature started at 80 degrees F., rose to 100 degrees F., and then dropped off again. The voltage curves show the highest and lowest of six cells tested in series. These curves hold close together for two hours and 37 minutes, or until the cells began to gas under the maintained finishing rate, when they separated somewhat, but not seriously. The voltage curves are quite straight for the two hours and 37 minutes and between 2.38 and 2.28 volts per cell. The approximately constant voltage shown by these curves suggests that the constant voltage method of charging will approximate the characteristics given in the above rule, and that if the voltage and number of cells be chosen so that 2.3 volts be used per cell, the charging will automatically follow closely the maximum permissible rate.

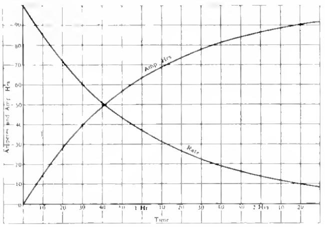

FIG. 4—THEORETICAL VARIATION IN CHARGING RATE

When the charging rate in amperes equals the ampere-hours out of the battery.

$R = C\varepsilon^{-t}$

The curves in Fig. 6 show the charge characteristics of a battery at constant voltage of 2.3 volts per cell when the battery is 25, 50, 75 and 100 percent discharged at the start of charge. This method of charging a battery is ideal, as it requires no attention after it has been connected to the charging circuit, and it puts in a large part of the charge in a short time, making the battery again ready for service with a considerable addition to the available stored energy.

Many automobile trucks are now charged in this manner whenever they are standing at their loading platforms. One-third of the ampere-hours used per day are frequently charged into the battery in this way without the loss of any time from actual service. At times of especially heavy service, as during severe snow storms, or during the holiday season, this adds materially to the usefulness of the truck. The curves already shown approximate the maximum permissible rates of charge, but these rates, especially during the early parts of the charge, are often in excess of values that are necessary or even commercially advisable, as limits below these values are frequently imposed by the amount of power available for charging and by the capacity of circuit and vehicle wiring.

The load factor of charging a single vehicle in this manner is very low, but if taken on a large system, as in a large garage or at an industrial plant using a large amount of electric power, its effect may be negligible commercially. Large garages housing electric cars only are using the constant voltage charging system, or a slight modification of it, with great satisfaction. In some cases a small resistance is used during the early part of the charge to reduce the current to an amount that can be safely carried by the wiring of the cars and the garage circuits. In other cases two bus voltages are used, each battery being charged from the low bus at about 2.2 volts per cell during the early part of its charge and from the high bus at 2.3 volts per cell during the latter part of the charge. Where there is a comparatively large number of vehicles to be charged, it is an easy matter to keep both machines loaded by transferring batteries from the low bus to the high bus and connecting additional batteries on the low bus as the current taken by the first batteries automatically falls off. An additional feature in favor of the constant voltage charging of batteries lies in the fact that no energy is lost in controlling resistances.

In case the available charging voltage is too high for the number of cells on the vehicle the excess voltage may be absorbed in counter electromotive force cells. These cells are similar to storage battery cells, except that the plates consist of lead alloy with no active material. These cells offer to the charging current an opposing voltage of 2.8 to 3 volts per cell, which is approximately constant and independent of the current flowing through them. A metallic resistance should not be used if the constant voltage charging characteristics are desired, on account of the variation of the opposing voltage with the charging current.

In cases when the low load factor caused by high rate charging is objectionable, lower rates of charging must be used and a correspondingly longer time will be required for the same input to the battery. Under many circumstances, this is in no way objectionable, as ample time is frequently available for all charging to be done at low rates. If there is sufficient time, all charging may be done at the finishing rate recommended by the manufacturers, or at any combination of rates that does not violate the general rule for permissible rates given above.

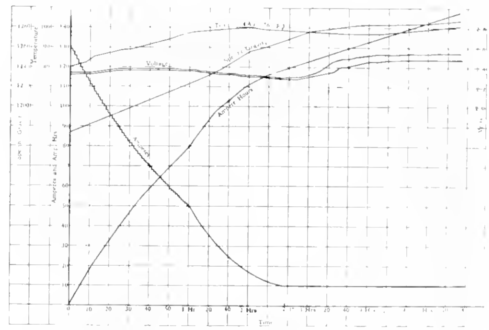

FIG. 5—ACTUAL CURVES OBTAINED BY CHARGING A BATTERY IN ACCORDANCE WITH THE RULE GIVEN UNDER FIG. 4

The charging current was kept for one-minute intervals equal to the ampere-hours discharge. The charge followed a discharge of 25.75 amperes for five hours, or 120 ampere-hours.

It is evident that very wide latitude for proper charging is offered from which to select the best way to charge a battery under any given local conditions. If the vehicle is equipped with an ampere-hour meter the readings of this meter may be taken as the basis for selecting a charging rate which may be used for a particular length of time, so that at the end of that time the charging rate will be at the maximum permissible rate, at which time the rate should, of course, be reduced. It follows from the general rule for charging that, if R = permissible charging rate, D = ampere-hours out of the battery at the start of the charge (reading of the ampere-hour meter) and T = time in hours until the current can be adjusted, then $R = D \div (1 + T)$ = maximum permissible charging rate for T hours, and at the end of T hours the charging rate will equal the reading of the ampere-hour meter. This value can again

TABLE I—CHARGING RATES

Ampere-Hours Discharged	Time Available until next Adjustment of Charging Current.							
	1/4 hour	1/2 hour	3/4 hour	1 hour	1 1/4 hours	1 1/2 hours	1 3/4 hours	2 hours
	Amperes	Amperes	Amperes	Amperes	Amperes	Amperes	Amperes	Amperes
10	8	6	5	5	4	4	3	3
20	16	13	11	10	9	8	7	6
30	24	20	17	15	13	12	11	10
40	32	26	23	20	18	16	14	13
50	40	33	28	25	22	20	18	16
60	48	40	34	30	26	24	22	20
70	56	46	40	35	31	28	25	23
80	64	53	45	40	35	32	29	27
90	72	60	51	45	40	36	33	30
100	80	66	57	50	44	40	36	33
110	88	73	63	55	49	44	40	37
120	96	80	68	60	53	48	43	40
130	104	87	74	65	58	52	47	43
140	112	93	80	70	62	56	51	47
150	120	100	86	75	67	60	54	50
160	128	106	91	80	71	64	58	53
170	136	113	97	85	75	68	62	57
180	144	120	103	90	80	72	65	60
190	152	127	108	95	84	76	69	63
200	160	133	114	100	89	80	73	67
210	168	140	120	105	93	84	76	70
220	176	147	126	110	98	88	80	73
230	184	153	131	115	102	92	84	77
240	192	160	137	120	106	96	87	80
250	200	167	143	125	111	100	91	83

EXPLANATION.—In the left hand column find the figure nearest to the ampere hours discharged from the battery, follow across to the column headed by the available time. The figure at this intersection is the current to be used.

EXAMPLE.—Ampere hour meter reading, 103 ampere hours discharged; time available for boosting, one hour. Start at 100 in the left hand column; follow across to the column headed 1 hour and find 50, which is the current to be used.

be divided by $1 + T$ for the new charging rate, and so on until the charge can be finished at the finishing rate. If it is desired to charge the battery rapidly, the time T should be taken as short as possible. For convenience Table I calculated from this formula is given. This table is of use not only in the charging room, but also for the determination of the best manner for charging vehicles under any contemplated conditions and for the selection of charging equipment to meet the requirements of these conditions.

It should be carefully noted that if an ampere-hour meter is made the basis for charging a battery, care must be taken to be sure that the meter indicates as nearly as possible the real state of charge of the battery. An accurate record of the ampere-hours discharge from a battery does not give an accurate measure of the ampere-hours necessary to fully recharge it, for there are certain variable losses in the battery which the ampere-hour meter cannot measure. In fact, there is no accurate way to predetermine exactly how many ampere-hours charge may be necessary to fully charge a battery, nor is it necessary in ordinary service that the battery be really completely recharged daily. An ordinary clock is not an accurate instrument for measuring time, yet if it is set correctly occasionally it is sufficiently accurate for ordinary purposes. It is the same with an ampere-hour meter. It is necessary that a battery be fully charged occasionally, say once a week, if the battery is subjected to hard daily use, as on a commercial truck, and this furnishes an opportunity to set the ampere-hour meter.

A battery is fully charged only when all the sulphate has been driven out of the plates into the electrolyte, and this is most easily indicated by the specific gravity of the electrolyte. As long as sulphate is being thrown out of the plates into the electrolyte during charge, the specific gravity of the latter must continue to rise, and when the rise stops the battery is fully charged. Most battery manufacturers recommend that a battery be given such

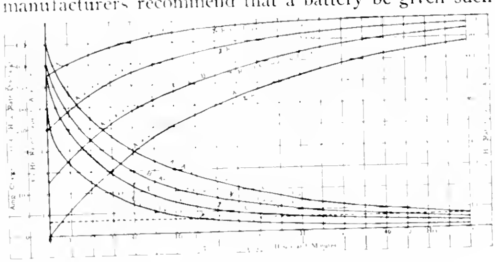

FIG. 6—CHARGING CHARACTERISTICS

Of Ironclad Exide battery at a constant potential of 2.3 volts per cell.

Ampere-hour efficiency 95 percent.
Five-hour rate = 92 percent of 4.5 hour rate.
Five hour rated capacity 102 percent of 4.5 hour rated capacity.
Temperature of electrolyte at start 80 degrees F; at finish 96 degrees. The charge can be completed in minimum time by raising the voltage sufficiently to hold the current constant when the finishing rate is reached.

a charge (called an equalizing charge), regardless of the indication of the ampere-hour meter, once a week or once in two weeks. When it is known that the battery is full, the charge is discontinued and then the meter is set to indicate a full battery, and the meter is then a sufficiently accurate indicator of the state of battery charge to be used for a week or two weeks until another equalizing charge is given the battery, when the meter should again be set.

Ampere-hour meters require cleaning and regulation at intervals as does a clock, and if they are treated in this manner they are of great assistance in the proper handling of a battery. These meters are frequently furnished with a contact making device so arranged as to interrupt the charging circuit when the meter indicates that the battery is fully charged, and this is a valuable protection against unnecessary charging and gassing of the battery during ordinary operation. This tripping device should, of course, be disconnected during the equalizing charge.

The Trackless Train

G. W. Bulley
President,
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THE PROBLEM of the trackless train presents many interesting features and has given engineers much food for thought. The enormity of the field opened up by this new system of haulage can hardly yet be grasped, and is certainly not realized even by the industrial public. The sight of a train of twenty or even of five cars winding in and out narrow aisles, around corners, among pillars, along floors already congested apparently to the limit of capacity, tracking perfectly and following a miniature self-contained motor-driven haulage unit with no rails to guide them, would astonish all but the initiated, and yet this is common in many large establishments today.

TO ACCOMPLISH tractor haulage the first consideration is the proper power unit, and from a commercial viewpoint naturally that unit is the one that will do a maximum amount of work at a minimum expense. It is obvious, therefore, that while certain essential elements are requisite in all designs, no one machine could be exactly suited to meet conditions which vary so greatly, and are never exactly alike in any two installations. As all available energy is stored and must be carried on the machine the lowest possible current consumption is of special importance. Small turning radius and compactness is sought because floor space is valuable and working places congested. Other indispensable qualities are extreme simplicity, coupled with reliability and accessibility, for in case of failure of the machine it is seldom that sufficient men are immediately obtainable to do its work.

In general, industrial tractors may be divided into three classes, namely:—

Industrial—Intended chiefly for interior work;

Semi-industrial—A heavier and larger machine than the industrial tractor, capable of yard, dock and to a limited extent interplant street haulage;

Semi-tractor—Which as its name would indicate is only part tractor, as a portion of the load is supported by the haulage unit, bringing it in reality in the truck class. The semi-tractor is seldom found in this line of work—with one exception, described later.

The industrial or carrier truck is in no wise a tractor, although it has been employed as such from time to time without marked success, easily accounted for by the limited motor and battery capacity, and design never intended for such work. The machines in general use are true tractors, varying in capacity from 3 to 15 tons under working conditions, rated by drawbar pull, the maximum generally being quoted.

It is to be regretted that this method of classification, which is the only true rating, is of little value to the prospective purchaser, as he has but scant knowledge of the application of the term to practice. On the other hand, if machines were classified by tons it might well be misleading to the buyer or unfair to the machine, the reason being that drawbar pull required per ton load varies so greatly with working conditions, such as road surfaces, grades, types of carrier, etc., as to require study before a classification in tons capacity as applied to the case can be made. It will be seen that a three-ton machine in one place may rightly be employed as a six-ton machine under more favorable circumstances, the maximum drawbar pull required being about equal in both cases.

MOTORS AND CONTROL

One of the determining factors of capacity is the motor and, as all industrial tractor manufacturers but one, so far as is known, use but a single size and make but one machine, it is apparent that many cannot be working to the best advantage. To date all too little attention has been paid this important member, as ampere readings taken from different makes of tractors under the same conditions show an astonishing variation in current drawn. This would indicate that some of the motors were not designed for the purpose, but selected more or less at random from the large assortment on the market. Regarding the motor, this much is certain,—it must have great overload capacity, unusually large commutator area and the shaft should be mounted on ball bearings. The capacity, winding and general design must be worked out to meet requirements.

There is nothing individual about the controllers, as those used in vehicles are largely represented. To them, however, are often attached safety devices which are more or less unique, though they are not a universal feature and are omitted entirely in the semi-industrial type. Some of the more interesting operate as follows:—A strong spring is placed to return the controller handle to neutral and a separate switch is mechanically connected to a foot pedal, which is also attached to the brake applied by a spring when the tractor is not in use. Pressure on this pedal releases the brake and throws in the supplementary switch. The same arrangement is found in other machines, except that the spring returning the controller to neutral is omitted. In another device, the controller is returned to neutral and brakes applied when the operator leaves the seat. When the operator is in position, the controller is free and a regular foot brake pedal is placed in convenient position for his use. The brakes may be permanently set by means of this pedal.

METHODS OF DRIVING

In the drive from the motor to the rear wheels there are the three types commonly found in the commercial truck, namely, chain to jack shaft and chains to rear wheels, gear or chain to rear axle driving shaft, which carries a bevel gear, and the single worm gear reduction.

There has been some attempt at four-wheel drive, but it is understood that this machine is no longer manufactured. It would seem entirely unnecessary to resort to this type and introduce the complications inherent to this drive, for the simple reason that sufficient traction may be obtained by placing the major portion of the battery weight, which must be carried in any event, over the driving wheels. All driving shafts are mounted on

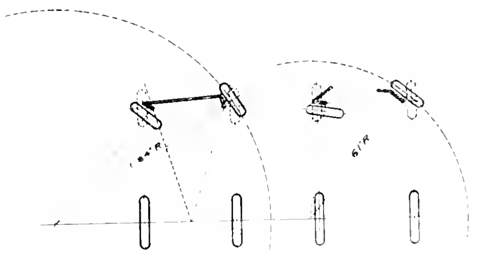

Fig. 1—Ordinary drag link with two-wheel steering
Fig. 2—Special steering arrangement

high-class ball or roller bearings, which must have unusually large overload capacities, more particularly the thrust bearing back of the worm, which drive is now quite general.

In the smaller types the batteries are spring suspended, but the chassis is not, as it is ordinarily used on good hard smooth floor surfaces. In some cases the battery trays are supported between springs to take the rebound, this being the best practice. The larger machines are spring hung, the intermediate sizes generally having spiral springs and the semi-industrial half elliptic.

METHODS OF STEERING

In the industrial tractor there are four forms of steering gears, and in the semi-industrial but two. The ordinary automobile drag link connection with two-wheel steer is represented with results as shown in Fig. 1. Unfortunately it is necessary in rounding a curve with a four-wheel machine to turn the inside wheel through a greater angle than the outside wheel. To approximate the correct angle a line is drawn from the pivot point of the steering knuckle to the center of the rear axle. When the wheels are in the straight running position, the drag link will be parallel to the axle, and if connected to the steering arms at the point where the lines drawn intersect the drag link either in front or behind the axle a fair compensation for angle will be obtained. If the wheel base is shortened, however, the angle formed by the steering arm and the drag link becomes more acute, so that with the industrial tractor wheel base it is very noticeable; in fact, is so great that the wheels cannot be turned as far as they should be and again returned to the straight position. The result is that the best possible turning radius cannot be obtained with this arrangement. In order to get the best turning radius a vertical plane on a line drawn through the center of the spindle of the inside front wheel should cut a vertical plane passing through the rear axle center just inside the rear wheel, as indicated in Fig. 2. By a very simple arrangement of levers this has been accomplished by one concern building industrial and semi-industrial equipments, with the results that the turning radius is equal to that of a three-wheel machine and wheels are more nearly in correct position at all times than when a regular drag link connection is used.

There are two three-wheel tractors on the market, one industrial and one semi-industrial, the first driving on the back wheels and steering with the front only. In this case the steering connection is direct. The second drives and steers on the front wheel, the drive being accomplished by a motor located inside of the wheel and the steer by a gear connection from the driver's seat, as in Fig. 3. The industrial machine of the three-wheel type may be headed straight into a post and, if the front of the machine has 3/4 inch clearance, it will turn around without backing and will not strike the post. It is very effective and perhaps the best possible design for inside work.

The four-wheel steer, while giving a fairly short turning radius, as shown in Fig. 4, has two distinct disadvantages, the first being the mechanical complication of driving and steering with the same wheels; the second, that if the machine is close against and parallel to a wall or other obstruction and is started away from it turning sharply, the rear end heads into the wall instead of away from it. This, of course, is no disadvantage except in confined places, but most working places unfortunately are confined.

BATTERIES

The usual battery capacities in machines available are 150 ampere-hours at 40 volts, and 225 ampere-hours at 30 and 42 volts. For some time one concern put out a machine having a capacity of but 150 ampere-hours at

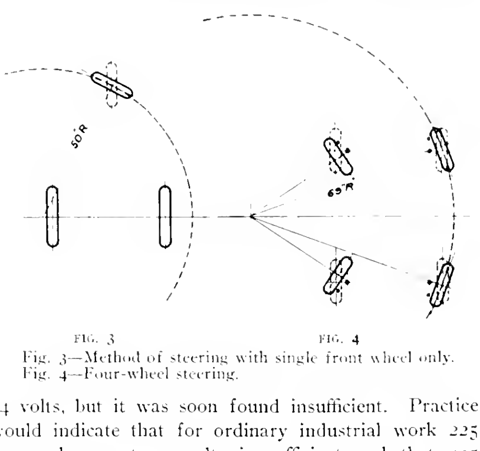

Fig. 3—Method of steering with single front wheel only.
Fig. 4—Four-wheel steering.

24 volts, but it was soon found insufficient. Practice would indicate that for ordinary industrial work 225 ampere-hours at 30 volts is sufficient and that 225 ampere-hours at 42 volts is ample for a ten-hour day. When necessary to operate 20 or 24 hours it is customary to change batteries, which may be done in two min-

utes time by special arrangement of battery container and slip connections. The semi-industrial machine is generally 60 volt and from 300 to 450 ampere-hours capacity.

The battery to use in this work seems to still be an open question. The general types are plain lead-plate acid battery, the acid battery with the "pencil positive plate" and the alkali nickel-iron cell, each possessing its

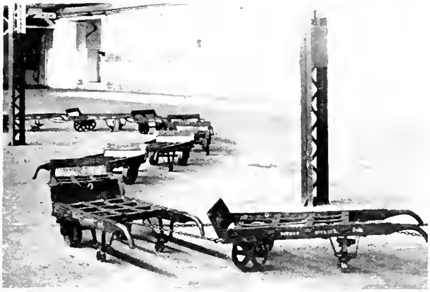

FIG. 5—TWO-WHEEL HAND TRUCKS ARRANGED AS TRAILERS

individual advantages. The acid battery is not so affected by cold, is more efficient and less expensive than the alkali type. It will also permit of a heavy discharge rate when necessary on account of its low internal resistance. The "pencil type positive plate" is more expensive and, while more durable, will probably cost about the same as the plain lead-plate in the long run. The alkali battery is much more durable, requires less care and is lighter than the acid battery. In all fairness it must be stated that while these cells are affected by cold to a greater extent than the acid cell they are easily protected. There is not a great deal of difference in cost at the end of a number of years service, no matter which cell is used. The cost to the consumer of a certain size of the three types of batteries would be as follows,—$281, $305 and $600. Most users seem to be willing to make the higher initial investment.

Some few machines are yet made with ordinary open wiring, some are wired in loom, and one at least in metal conduit filled with asphaltum after the wires are in place, making all of them a unit and obviating any chance of wear due to vibration, and allowing the removal of the wires in a single piece, as they are fastened in place with but two bolts. The outlets are so arranged that no wiring diagram is necessary, and the controller, motor, switch or any other part may be removed or replaced without any likelihood of making improper connections.

TRAILERS

The trailer equipment for these machines might well be described as "anything on wheels." When an installation is made it is quite usual to prepare hitches and use the equipment already available, and it is seldom possible to design or have the users purchase new or special trailers. If the problem is difficult where equipment can be specified, it is doubly so where old equipment must be utilized. Fig. 5 illustrates the method of handling two-wheel hand trucks as hand trucks and trailers. A patent has been granted on this type of carrier. If necessary, even wheelbarrows may be towed in trains of any number. It is seldom possible to use the same hitches on any two installations, because the same trailers are rarely found and, even if the trailers are alike, it might seem wise to use a different hitch on account of other conditions. Hitches may now be worked out to a nicety with a blue print of the trailer on hand, but it is best to have a clear idea of the installation before attempting this work. Among the hitches already employed are found the cross bar, cross chain, triangle chain, triangle bar, double triangle of both kinds, and two more or less automatic hitches. It would be impossible to discuss this subject in detail in the space available, but the automatic couplings are well worthy of note. One of these, shown in Fig. 6, somewhat resembles a railroad coupling. This coupling will operate through a considerable angle and will automatically couple if trailers are not over $3\frac{1}{2}$ inches out of line on either side of center. The other coupling, Fig. 7, will couple up automatically if the trailers are pushed together with a leeway of 24 inches side motion and at an angle of 60 degrees either side. Uncoupling is accomplished by a foot pedal on the tractor or a hand lever on the trailers. These hitches are great time-savers and are fast coming into their own. It must be remembered when designing a hitch that not only the usual drawbar pull exerted to start a trailer and others

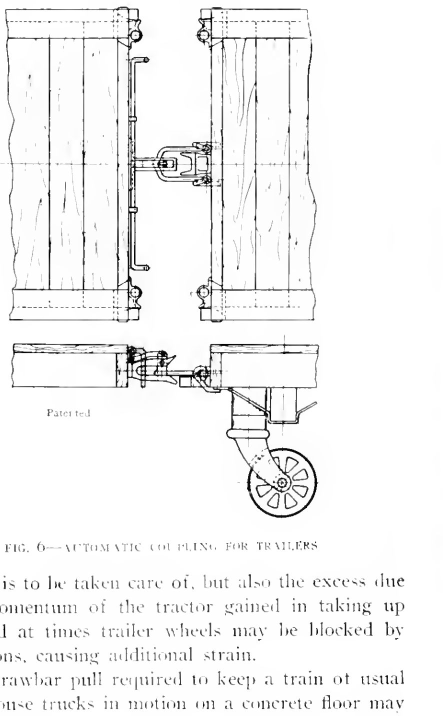

FIG. 6—AUTOMATIC COUPLING FOR TRAILERS

behind it is to be taken care of, but also the excess due to the momentum of the tractor gained in taking up slack, and at times trailer wheels may be blocked by obstructions, causing additional strain.

The drawbar pull required to keep a train ot usual freight house trucks in motion on a concrete floor may

be taken as 65 lbs. to the ton trailer and load. This will be reduced by roller or ball bearings and increased on less favorable surfaces. It is also increased by 17.5 percent per one percent of grade, so that a ten percent grade will necessitate an additional drawbar pull equal to 175 percent of the original. Only on account of the wonderful flexibility of the tractor trailer method of haulage has this system gained its present position.

Transportation engineers have always realized that placing the load directly on an expensive power unit, with the unavoidable delays at loading and unloading points, did not make for economy or, if a saving was effected, it was but a small portion of that possible. To

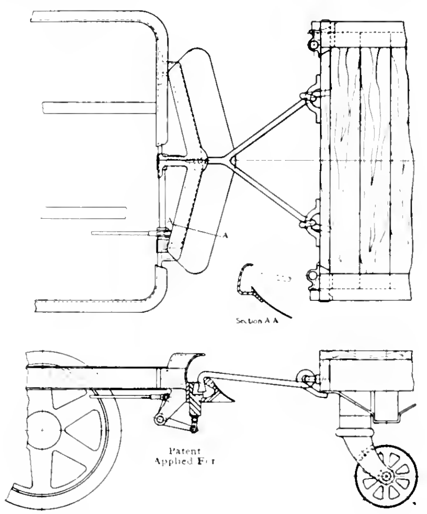

FIG. 7—ANOTHER TYPE OF AUTOMATIC COUPLER FOR TRAILERS

overcome this, and it has done so to a certain extent, the "lift truck" was devised, when other difficulties arose. Unfortunately the loads became immovable without the carrier, which therefore had to be on hand when required, as quite often machines were being fed and were turning out their work to racks which the carrier picked up and moved. A tractor hauling but a single trailer is therefore more desirable.

TRACTOR OPERATING COSTS

In considering tractor costs and tractor trailer savings, it is natural to compare it with the old-established hand-trucking methods. A few specific cases will answer as illustrations. In these the total cost of operation and maintenance of the small industrial tractor is less than $2 per day, and may therefore be taken as the cost of a single man. In computing tractor cost the depreciation is put at 20 percent, interest on investment at six percent, current at three cents per kw-hr., and insurance, renewals and repairs are included generously in this figure.

The first illustration is an installation of a single machine in the basement of a general merchandise concern where the greatest haul is in the neighborhood of 1800 and the average 900 feet. The trailers are six-wheel "empty box" trucks formerly pushed by hand. They are 4 feet wide, 8 feet long and 7 feet high when loaded. It is a daily occurrence to see a train of from 19 to 22 of these trailers, a train 196 feet long, exclusive of tractor, making the several turns, some of them in "S" form. It was originally intended to haul six to eight trailer trains. This machine is now displacing 13 men who were formerly the pushers. It will displace several more, and will also do away with a power conveyor when an incline leading to the street is completed.

Another tractor is handling less than carload freight on three 16 foot platforms about 900 feet long, with a row of posts down the center and bridges across from one platform to the next during loading and unloading periods. The average haul was 880 feet. The machine handled 65 tons per hour, displacing 18 to 20 men, who average but 3.3 tons per working hour each under fair conditions. The power taken for 3.6 days of 10.5 to 11 working hours was 55 kw-hrs., costing the consumer one cent per kw-hr., an average of 13 cents per day.

A record of actual saving on another platform shows a gain of $1048 per machine per month, which is well toward the purchase price. In each of the cases cited only pushers were eliminated, but quite often labor savings are noted in other directions.

In a certain mill in the middle west, one haul is a good example of the practice of "keeping the material on wheels." The haul of 2100 feet is broken three times to allow the "material" to go through certain processes before reaching its final destination. The trailer train is loaded directly from a machine, carried 1000 feet and dropped to be fed to another. The tractor takes the train left on the last trip, returns it 600 feet to the stock room, picks up empty trailers, leaving the loaded train and returning to starting point, where another load is ready, then repeats its trip.

Pushers are, of course, eliminated, but it was previously necessary to employ a good number of laborers to load push carts from stationary racks. The double handling is now avoided, as the racks are on the trailers. The outlay for the system is roughly $30 000; the annual saving more than double this amount.

The semi-industrial tractor cannot always make as good a showing, because horses are often displaced as well as men, but a machine handling ten tons at five miles per hour, capable of working ten hours under full load 70 percent of the time and costing a trifle over $3.75 per day to operate and maintain, will accomplish much. On a wharf, horses were employed to haul what is termed "low down trucks," which are low-platform flat wagons with small wheels, made in this form for convenience in loading. The load is 2500 pounds per truck, and was handled by a horse and driver. A tractor here is capable of replacing eight horses and eight men.

The single case where the semi-tractor is preferable to the tractor is found in handling long bulky material when the frame of the machine is extended and a

pivoted cross arm attached on top of the extension. The material is carried on two wheels, the ends resting rather lightly on top of the cross arm, held in place by a strap or chain.

It is quite easy for an experienced engineer to tell whether a proposed installation will be practical and a good investment. The comparatively few failures recorded have generally not passed beyond the demonstration period and are directly traceable to the incompetency of salesmen to cope with engineering problems which arise. It is doubtful if the usual salesman has any place in this work, as mechanical knowledge and ability are more or less essential. The ramifications of this field of endeavor are enormous, as it covers the entire industrial world. One day it is a complicated freight platform, involving the entire system of checking as well as handling all sorts of merchandise; then the cellar of a packing house, with its greasy floors, crooked passages and disorder and congestion. The materials of warehouses, factories, foundries, mills, docks, wholesale houses, railroads, express companies and others too numerous to classify can, to a great extent, be handled with appreciable saving by this method.

When approached, the man at the head of a concern may recognize the advantages, but quite often will say, "It can't be done," adding that he is very familiar with his conditions. One of the hardest things to combat is the prejudice against change. Another is the natural antagonism of workmen who expect to be ousted and are not inclined to give any machine a fair chance under the circumstances. This is particularly bad during demonstration, as they will resort to anything from shirking to actual damage to the equipment. Not only is the tractor trailer method fast displacing the manual, electric truck and lift truck method, but on account of its great scope is also doing away with conveyors, industrial railroads, and like permanent, expensive and inflexible equipment. It is not in an experimental stage, but has demonstrated itself clearly a useful, valuable servant and has come to stay.

Charging Edison Storage Batteries

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Edison storage batteries may be properly charged by either the constant current or the tapering current method, both systems being recommended by the manufacturer with the assurance that equally good results may be obtained with either method when properly used. The constant current method of charging was adopted first and has been regularly used since 1909; the tapering current method is a relatively new development. Before proceeding with a detailed description of the charging methods, a brief description of the active materials used and the accepted theory of the electro-chemical action of the cell will undoubtedly prove of interest to those not familiar with this type of cell.

FIG. 1—FLEET OF WARD'S BREAD WAGONS, NEWARK, N. J.

The positive plate consists of perforated sheet steel tubes, nickel-plated and filled with alternate thin layers of nickel hydrate (active material) and flakes of pure

metallic nickel. The negative plate consists of thin rectangular perforated sheet steel pockets, nickel-plated and filled with iron oxide (active material). The electrolyte consists of a solution of potassium hydrate. The exact chemical changes that go on within the cell during charge and discharge are not definitely known. The following symbolic representation, however, is quite generally accepted:—

In discharge

$3\ Fe + 8\ (OH) = Fe_3O_4 + 4\ H_2O$ (negative)
$6\ NiO_2 + 8K + 4\ H_2O = 2\ Ni_3O_4 + 8\ KOH$ (positive)

In recharging

$Fe_3O_4 + 8K + 4\ H_2O = 3\ Fe + 8\ KOH$ (negative)
$2\ Ni_3O_4 + 8\ (OH) = 6\ NiO_2 + 4\ H_2O$ (positive)

The Constant Current Method of charging consists of maintaining a uniform charge rate throughout the entire charge period. This uniform charge rate should always be that rate recommended by the manufacturer as normal. Constant current rates below normal are not recommended, as experience would indicate that such rates do not effect a thorough deoxidation of the negative element. Low rates of this character will in no way affect the ultimate life of a cell, but the voltage on the subsequent discharge will be somewhat below normal. Normal charge and discharge voltage characteristics of a cell when charged by constant current method are shown in Fig. 2. When direct current is available, the usual garage equipment for charging batteries by constant current methods consists essentially of suitable ampere and volt meters and an adjustable rheostat. In laying out an equipment of this character it is wise to bear in mind that high boosting rates for short periods may be used. The following boosting figures may be used under normal conditions:—

5 minutes at five times normal rate
15 minutes at four times normal rate
30 minutes at three times normal rate
60 minutes at two times normal rate

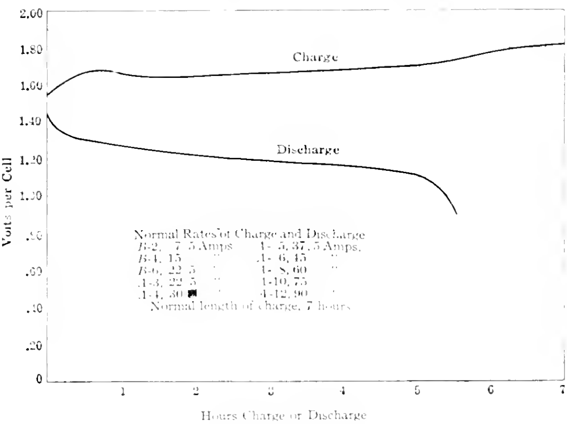

FIG. 2—NORMAL CHARGE AND DISCHARGE VOLTAGE CURVES

The voltmeter scale should be such as will record the maximum line voltage; and the ammeter scale should be such as will record the maximum current. The ohmic resistance of the adjustable rheostat may be determined by the following formula:—

$$\text{Total resistance (ohms)} = \frac{\text{Maximum line voltage minus initial battery voltage}}{\text{Current in amperes.}}$$

To determine the initial battery voltage multiply the number of cells by 1.55.

The Tapering Current Method of charging, now quite extensively used, is deserving of careful consideration, as numerous apparent advantages may be realized from its adoption. As might readily be supposed, there is a proper and an improper way of using this method. A proper tapering current charge is one in which the average current throughout the entire charge period is equal to the normal charge rate of the cell. An improper charge is one in which the average rate is either higher or lower than the normal cell rate. The general contour of a tapering current charging curve will vary according to whether fixed resistance is used. A normal tapering charge without any fixed resistance in the charging line is shown in Fig. 3. This result may be obtained when the voltage across the battery terminals is equal to 1.7 times the number of cells in the series. To allow for voltage loss in charging plugs, cables and lines, it is common practice to maintain an average of 1.73 volts per cell at the bus-bar of the charging line. If the voltage at the bus-bar exceeds an average of 1.73 volts per cell, a fixed resistance must be placed in the circuit. To provide for possible line voltage variation, and also for the effect of low electrolyte temperatures, it is wise to have this unit built with two or more screw taps in order that adjustments may be made should the occasion ever require. These taps should be so located that an average of 1.75 or 1.77 volts per cell might be obtained at the switchboard end of the charging line. Ohm's law is used to determine the amount of fixed resistance. Assume, for example, that it is desired to charge a 60 cell Type A-4 battery from a direct-current line, the voltage of which is 115 volts at the bus-bars. Bearing in mind that the normal charge rate for this type is 30 amperes, the proper resistance unit can be determined as follows:—

$$\frac{115 - (60 \times 1.73)}{30} = 0.373 \text{ ohms}$$

It should be borne in mind that the proper ohmic resistance of a charging unit of this character decreases as the size of cell to be charged is increased. For example, for the above-mentioned condition, but with a Type A-6 battery, the charging rate of which is 45 amperes, the formula would be

$$\frac{115 - (60 \times 1.73)}{45} = 0.248 \text{ ohms}$$

This feature, if not provided for, is liable to prove troublesome where different size cells must be charged from the same line. Under these latter conditions it would be most convenient to supply a variable type rheostat, each step of which could be marked for the battery combination for which it was designed.

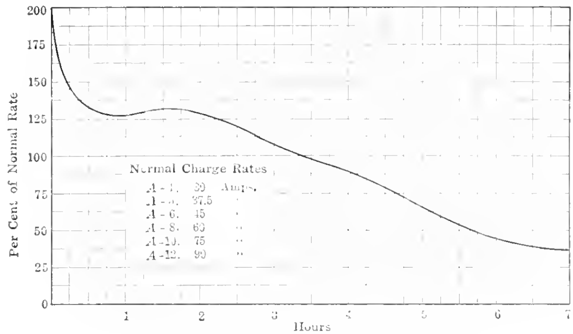

FIG. 3—CURRENT CURVE WITHOUT FIXED RESISTANCE
1.7 volts per cell.

The current characteristics of a cell when the voltage at the bus-bar averages 1.84 volts per cell is shown in Fig. 4, the proper fixed resistance being used. As the amount of fixed resistance is increased the current curve flattens out very materially.

The advantages claimed for the tapering current method are obviously very valuable. First, hand rheostat adjustment is eliminated, thus effecting a savings in garage labor. Second, gassing and consequent evaporation of the electrolyte are materially reduced, thus prolonging the interval between flushing periods. Third, in many cases the commercial watt-hour battery efficiency is improved upon as the watts dissipated in an adjustable rheostat are utilized. Fourth, the tendency to unnecessarily overcharge is very largely eliminated, as the last part of the charge is given at a comparatively low rate, and if a battery should be left on charge too long the waste would be greatly reduced.

If an ampere-hour meter is used, regardless of the method of charging adopted, the meter should be set to operate 20 percent slow on charge, as experience has proved that 80 percent ampere-hour efficiency can readily be obtained in service.

One of the most recent large installations of electric delivery cars, the batteries of which are charged by the tapering current method, is that of the Ward Baking Company at East Orange, New Jersey. This fleet consists of eighty cars, all of which were built by the Ward Motor Vehicle Company [illegible] non, New York. Fifty-two of these car[illegible]d carrying capacity of 1000 pounds, eighteen [illegible] capacity of 2000 pounds, and the other ten [illegible] "Ward Special" type, with a rating of [illegible] pounds. All of these batteries are [illegible] with 65 cell Edison batteries and Westinghouse motors and controllers. This company manufactures its own direct current and maintains approximately 115 volts at the bus-bar of the charging board. Each charging line is provided with a fixed resistance unit of 0.2 ohms and a short-circuiting switch for each resistance unit. Unfortunately, the engine capacity of this plant is not sufficient to permit of the starting of the charge with all resistance cut out, consequently it has been common practice to start the charge with the resistance units in circuit and to cut them out after the batteries have been on charge for about thirty minutes.

This method of charging has been used from the start, and has proven to be a great success. One very interesting fact observed by the garage attendants is that the condition of charge can be quite accurately determined by the ammeter reading. For example, when the current on a 65 cell Type G-4 battery falls to 10 amperes it is an indication to them that the battery has reached a state of full charge. This fleet serves seventy-two routes, the average mileage of which is twenty-nine, or a total of 2088 car-miles per day. The average daily kw-hr. input per car is 17.3, or a total of 1250 kw-hrs. When it is considered that most of the routes covered by these cars are quite hilly, and that no particular effort has been made to economize on current consumption, it will be realized that this method of charging automatically effects power economy.

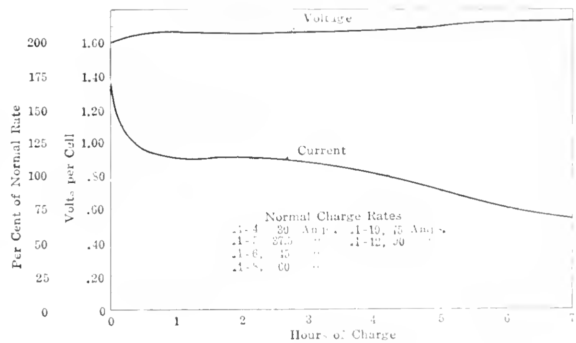

FIG. 4—VOLTAGE AND CURRENT WITH FIXED RESISTANCE IN CIRCUIT
1.84 volts per cell

Battery Charging Equipment

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THE application of equipment to be used for charging storage batteries is a problem subject to many premises, and the solution must of necessity be a compromise. In order to understand thoroughly the problems involved it is necessary to have a knowledge not only of the electrical characteristics of the various types of storage batteries in use, and of the circumstances and conditions under which the charging is to be done, but one must also be acquainted with the standard electrical equipment available for such applications.

NOMENCLATURE

A storage battery is made up of a number of cells, each composed of a glass or rubber jar containing a number of plates immersed in an electrolyte, all plates of like polarity being connected together at the top by metallic conductors. The term "battery" signifies a number of cells connected together electrically. The discharge and charging rates (in amperes) of a cell depend upon the size and the number of plates in that cell.

TYPES OF BATTERIES

In general, there are two distinct types of storage batteries in use today, namely, the nickel-iron (Edison) and the lead type. The nickel-iron type is an alkaline battery, as the active elements consist of metallic plates immersed in a dilute solution of potassium hydroxide (caustic potash). The active material of the positive plates is peroxide of nickel; the active material of the negative plates is iron oxide. The lead type is an acid battery, as the active elements consist of plates immersed in a weak solution of sulphuric acid. The active material of the positive plates is peroxide of lead, and the active material of the negative plates is metallic spongy lead.

There are two classes of lead batteries, the Plante and the Faure or pasted type, named after their inventors. In the Plante class, the active material of the plates is formed from the integral lead of the plates, or from metallic lead embedded in the plates, by a cycle of charges alternating with discharges at comparatively low rates. In the Faure or pasted class, the plates are comprised of strong alloy grids or frames in which a paste of the active material is pressed. The electrical characteristics of these two classes of lead batteries are so similar that both will be treated under the general term of lead batteries.

RATING OF CELLS

Storage battery cells for electric vehicle service are rated on the basis of the number of amperes which they will discharge continuously for a definite period of time, ranging from three to six hours, depending on the type of cell, and the service for which it is designed. Cells for stationary service and car-lighting service are usually rated on the eight-hour basis. Therefore, if a battery for such service is specified as having 240 ampere-hours capacity, it is customary to consider that the rating is on the eight-hour basis, unless otherwise specified.

In specifying lead cells by the ampere-hour capacity, it is necessary to know the time basis of the ampere-hour rating, because the ultimate capacity* of a lead cell is inversely proportional to the discharge rate in amperes or is directly proportional to the length of time. For example, a certain lead cell is rated at 30 amperes for eight hours, or 240 ampere-hours. This same cell may be discharged at 60 amperes for three hours, or only 180 ampere-hours. The ampere-hour capacity of an Edison cell is also inversely proportional to the discharge rate in amperes, or is directly proportional to the length of time during which the battery is discharged.

METHODS OF CHARGING BATTERIES

In general, there are two distinct methods in use for charging both the nickel-iron and lead batteries manufactured for electric vehicle service. The first method, and the one most widely used at the present time, is known as the constant current method. The second method, which has only recently come into use, is known as the constant potential method. There are also two other schemes, which are used for battery charging, generally known as the double or multiple voltage system and the fixed resistance method. These two schemes, however, are in reality not distinct methods, as they are merely modifications of the two general methods.

CONSTANT CURRENT CHARGING CHARACTERISTICS

Edison Batteries, in the constant current system, are charged at a constant current rate for the entire charging period by frequent adjustments of the impressed voltage. The normal charging rate for an Edison battery is the same as the normal discharge rate in amperes. The length of time required to completely charge the battery depends upon the state of discharge prior to the charging period. A battery, which has only been partially discharged prior to the charging period, should be charged at the normal rate until the voltage remains approximately constant for a period of about 30 minutes. An Edison battery may be boosted at rates higher than normal for short periods of time, providing

*See article by Mr. J. H. Tracy, Fig. 1, p. 17.

the temperature of the battery does not exceed 115 degrees F.

Lead Batteries manufactured for electric vehicle service are usually charged at a fixed rate (known as the starting rate) until the battery begins to gas or bubble and the battery voltage has reached a certain value: then the current is reduced to another fixed rate (known as the finishing rate), at which it is maintained until the specific gravity of the electrolyte ceases to rise. The length of time required for the charge depends upon the state of discharge of the battery prior to the charging period. An Ironclad-Exide battery (if completely discharged) will require about five hours at the starting rate and two hours at the finishing rate in order to completely charge the battery. If the battery has been only partially discharged, the length of time required for charging will be reduced.

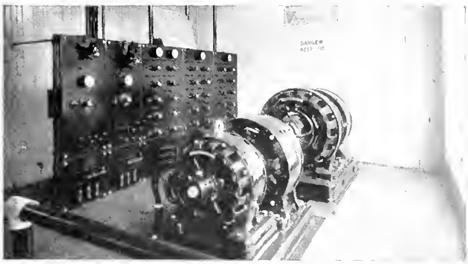

FIG. 1—BATTERY CHARGING OUTFIT

This equipment is located in the show window of the Peoples Garage & Auto Livery Company, Chicago, Ill., as a special advertising feature. One set is composed of a 25 kw, 125 volt generator and a 38 hp, three-phase, 60 cycle, 220 volt induction motor; the other of a 50 kw generator and a 75 hp motor. Each generator circuit is provided with a circuit breaker having an underload release attachment. Twenty-seven of the thirty battery charging rheostats are each designed to charge a 42 cell battery at a rate varying from 22 to 5 amperes; the other three are designed for charging a 42 cell lead battery at a rate varying from 45 to 18 amperes.

Lead batteries manufactured for electric vehicle service may be boosted at high rates for short periods of time, depending upon the ampere-hours out of the batteries.* The only limitations upon the rate at which a lead battery may be charged are, that the rate must not be maintained at a value sufficiently high to gas the battery unduly or increase the temperature of the electrolyte above 110 degrees F.

Lead batteries used in stationary and car-lighting service are usually charged at a rate corresponding to the eight-hour discharge rate of the battery. At this rate about nine hours are required to completely charge a fully discharged battery. Such batteries may, however, be charged at higher rates within the gassing and temperature limits, as mentioned above.

CONSTANT POTENTIAL CHARGING CHARACTERISTICS

In the constant potential system the two types of batteries require charging equipments of greater capacities than are required for the constant current system, as the energy demand at the start of the charging period is very high. This system has two inherent virtues:—

First—High efficiency.
Second—All charging embodies ideal boosting characteristics or, to express it differently, a maximum charge may be put into the battery within a given time.

To charge an Edison battery by the constant potential method, the battery should have impressed upon its terminals a potential corresponding to 1.7 volts per cell,† under which conditions the charging current through the battery will taper from a high current at start to a low current at the finish of the charge. The length of time required to charge an Edison battery by this method depends upon its state of discharge prior to the charging period. When the charging current ceases to decrease appreciably and remains approximately constant for a period of 30 minutes to one hour, the charge is complete.

To charge a lead battery by the constant potential method, the battery should have impressed upon its terminals a potential of 2.3 volts per cell.‡ The current flowing through the battery will start at a very high rate and taper to a lower rate.

There are many advantages derived from the constant potential method of charging, among which are, the reduction in evaporation, the elimination of hand adjustment of series rheostats, the elimination of the tendency to overcharge, and an increase in the commercial watthour efficiency of the battery.

FIXED RESISTANCE CHARGING CHARACTERISTICS

Either type of battery may be charged by means of a fixed resistance connected in series. If the maximum battery counter electromotive-force is approximately equal to the line potential, then this method of charging will approach very closely to the characteristics of the constant potential method. If the maximum bat-

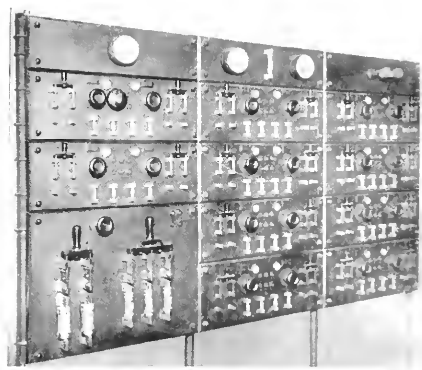

FIG. 2—BATTERY CHARGING BOARD

Of the Rauch & Lang Electric Car Company, St. Paul, Minn. Each rheostat is designed for charging 40 to 42 lead cells at rates varying from 30 to 5 amperes. Each of the twenty battery charging circuits is provided with a pilot light to indicate when the circuit is in use

*See Fig. 4 of the article by Mr. J. H. Tracy, p. 19, this issue.

†See Fig. 3 of the article by Mr. E. J. Ross, p. 27, this issue.
‡See Fig. 6 of the article by Mr. J. H. Tracy, p. 20, this issue.

tery counter e.m.f. is low compared with the line potential, the charging current will not vary over such a wide range and will approach the characteristics of the constant-current charging method. In other words, the range of variation in the charging current is inversely proportional to the difference between the maximum counter e.m.f. of the battery and the potential of the supply circuit.

CHARGING STORAGE BATTERIES IN SERIES

The practice of connecting storage batteries in series for charging is so hazardous that this question will be given only sufficient consideration to point out the dangers usually involved. In order to fulfill all the requirements of the best battery charging practice, batteries should never be charged in series unless all of them are composed of the same type, size and capacity of cells, and furthermore, all of the batteries are in the same state of discharge. For instance, if a single battery is comprised of two groups of cells, each group consisting of a number of cells in series and the two groups are connected together in parallel when discharging, then the two groups may be connected in series for charging without serious results. If a number of batteries, which are identically the same (namely, the same type, size and capacity of cells), but in various states of discharge, are to be connected in series for charging, particular attention must be given to those batteries which have been used least, so that they will not be overcharged. If, however, the batteries connected in series are of the same type, but have cells of different capacities, then the charging rate will be either too high or too low for some of the batteries. A battery of any type will not only be injured if charged at too high a rate, but also will not develop full rated capacity if charged at too low a rate.

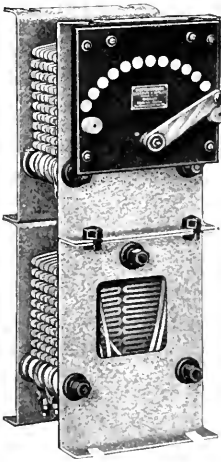

FIG. 3—BATTERY CHARGING RHEOSTAT DESIGNED FOR SEPARATE MOUNTING

A great many garages charge small batteries connected in series. This can only be explained in one of two ways. Either the dangers involved are not fully understood and appreciated, or the additional cost of maintenance and depreciation for such small batteries (when charged in series) is not considered as warranting the investment of capital in apparatus required for charging them separately, which also may actually increase the cost of power required for charging the batteries. It is evident, therefore, that the battery manufacturers and the manufacturers of charging equipment must hesitate to assume any responsibility for charging miscellaneous batteries connected in series, except in special cases, wherein all of the charging conditions and types of batteries to be charged are known.

CHARGING BATTERIES IN PARALLEL

Batteries charged in parallel, or any battery comprised of two or more groups of cells connected in parallel, or any battery which must be broken up into two or more parallel groups for charging, should be provided with an individual resistance or rheostat for each group of cells connected in series, when charged by the constant current method, with the following exceptions:—

An Ironclad Exide, or an Edison battery composed of a number of cells normally discharged in series, may be broken up into two or more groups of cells, said groups to be connected in parallel for charging. If all of the groups are composed of the same number of cells, the groups may be charged in parallel either direct from a suitable generator or by means of a suitable series rheostat when power is obtained from a constant potential line. Likewise, if either of these types of batteries are composed of a number of groups of cells, the groups being connected in parallel when discharging, then these groups may be charged in parallel, as explained above, or the groups may be reconnected in series for charging in the usual manner.

APPARATUS FOR CONSTANT-CURRENT CHARGING

All Edison batteries can be charged at the usual rates by a potential varying from 1.5 to 2.2 volts per cell, and all lead batteries can be charged at the usual rates by a potential varying from 2.1 to 2.7 volts per cell (at ordinary temperatures), regardless of the class (Plante or Faure) to which they belong.

If direct-current service of 110 volts is available, Edison batteries of 60 cells or less, and lead batteries of 40 cells or less, may be charged from the line by means of a rheostat in series with each battery. If direct-current service of 220 volts or higher is available, it is usually advisable to install a motor-generator set. If alternating-current service only is available, then a motor-generator set, or one mercury arc rectifier for each battery, must be installed. If one battery only is to be charged, and if the voltage of the generator can be adjusted over a sufficient range (by means of the generator field rheostat), then no series rheostat is required, as the charging current can be maintained at the proper value by adjusting the generator voltage. If a mercury arc rectifier is used for charging the battery, the current can be maintained at the proper value by adjust-

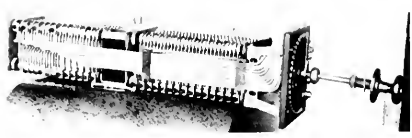

FIG. 4—BATTERY CHARGING RHEOSTAT
Designed for switchboard mounting on charging panel.

ments of the rectifier control dials without the use of a series rheostat. If a large number of batteries are to be charged by a motor-generator set or by a direct-current generator, then series rheostats must be provided, one rheostat being required for each charging circuit.

When selecting a generator or a motor-generator set and charging switchboard for the constant-current

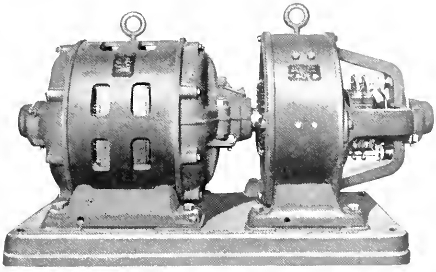

FIG. 5—TYPICAL MOTOR-GENERATOR SET FOR BATTERY CHARGING

method of charging, there are a number of points which must be given careful consideration.

1—The number of cells connected in series, of which each battery is composed, will determine the voltage of the generator.

2—The maximum and minimum charging rates required for each battery and the total number of batteries to be charged at the same time, will determine the ampere capacity of the generator.

3—The maximum charging rates of the individual batteries will determine the capacity of the apparatus for each charging circuit.

4—The total number of batteries to be charged, or the total number of batteries to be charged at one time, will determine the number of charging circuits and rheostats required for the switchboard.

5—Is reverse-current protection in the form of a low-voltage release circuit breaker desired for each charging circuit, or for the main line or generator circuit only?

6—Is reverse-current protection in the form of a low-voltage release circuit breaker and a sensitive* reverse current relay or sensitive* reverse-current mechanism desired for each charging circuit, or for the main line or generator circuit only?

7—Is it desirable to have any or all charging circuits equipped with apparatus which will automatically terminate the charge of each battery?

8—Is it desirable to provide equipment whereby the motor-generator set will be disconnected from the supply circuit when the charging of the batteries is terminated either by hand or automatically?

9—Is it desirable to provide equipment whereby the motor-generator set will be disconnected from the supply circuit upon the complete or partial failure of the power supply?

10—Is it desirable to have a watthour meter in each charging circuit?

11—Is it desirable to have each charging circuit protected by fuses, or by a single-pole circuit breaker and one fuse? In this case the circuit breaker will protect one side of the charging circuit and the fuse will protect the other side.

12—Is a single-pole or a double-pole switch required for each charging circuit?

13—Is it desirable to have the main line or generator circuit protected by fuses, or a circuit breaker?

14—What is the maximum permissible distance that the switchboard may be mounted from the wall, or objects, immediately behind the switchboard?

It is evident that the information involved in paragraphs (1) and (2) will determine the capacity of the generating equipment. For some installations more than one generator or motor generator outfit will be required either because of the large total capacity necessary or because more economical operation may be obtained from several units, having a combined capacity equal to the total capacity required. The initial cost and subsequent economy and convenience of operation of an installation is influenced to a marked degree by the selection of the proper switchboard and equipment as involved in paragraphs (3) to (14), inclusive.

The selection of the proper charging rheostats is one of the points often given the least consideration, and yet this is second only in importance to the selection of the generating equipment, as on this feature not only the economical and satisfactory operation of the installation, but also a considerable proportion of the first cost of the switchboard equipment, is dependent. If each of the rheostats has characteristics best suited for charging a battery of a certain capacity and a number of cells, then the rheostats will average about 25 percent of the total cost of the switchboard. If the rheostats have universal characteristics suitable for charging batteries of widely differing capacities and numbers of cells, they may represent as high as 50 to 75 percent of the total cost of the switchboard. Again, if the rheostats are designed for charging the batteries at unusually low or abnormally high rates, their cost will be proportionally higher than normal. If their characteristics necessitate the use of a large number of grids, the space available

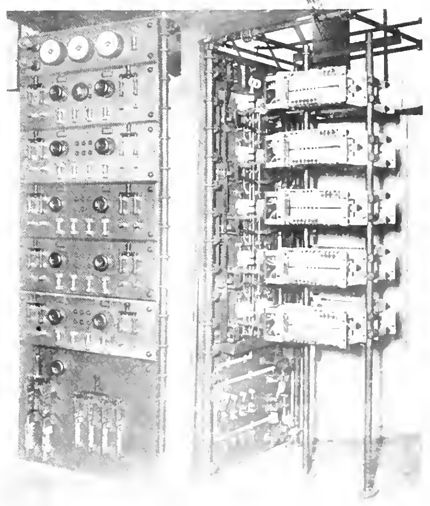

FIG. 6—BATTERY CHAR[illegible]

In use by the Pennsyl[illegible] Railroad Company, [illegible] delphia, Pa. There are [illegible] battery charging circu[illegible] rheostat is designed for [illegible] lead [illegible] start and 10 amperes fini[illegible] cells at 45 to 90 amperes, inclusi[illegible]

behind the switchbo[illegible]ate mounting the frames of resistors in [illegible] This, also, may necessitate the use of a blank section mounted either above or below each charging section to accommodate the assem-

*One functioning almost independently of variations of the line potential.

bly of the resistor frames behind the panels. Thus the size and cost of the switchboard will be materially increased. For example, assume a rheostat for a battery of 24 to 44 lead cells, or 40 to 60 Edison cells, requiring charging rates varying from 50 to 10 amperes based on a line potential of 115 volts. Such a rheostat will require 82 five-inch grids, assembled in four frames, each frame being approximately 24 inches long. If the frames are

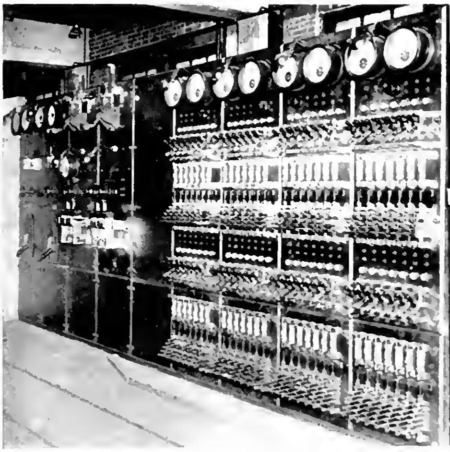

FIG. 7—BATTERY CHARGING OUTFIT
Of the Adams Express Company, Union Station, Washington, D. C. This board controls two motor-generator sets of 100 kilowatt capacity with three-phase, 60 cycle, 2200 volt induction motors. The generators are operated in parallel. Each battery charging circuit is provided with a pilot light which indicates when it is in use. A five-point switch is connected to the charging rheostat of each circuit in lieu of the customary face plate, the rheostats being designed for charging rates varying from 50 to 100 amperes.

mounted end to end, and are assembled behind the switchboard, the distance from the rear of the panel to the rear of the supporting frame work of the rheostats will be approximately seven feet. If, however, the four frames are mounted in two tiers (one tier above the other) of two frames per tier, then the distance from the rear of the panel to the rear of the rheostat framework will be approximately four feet. In this case, however, the height of each rheostat is greater than the height of a 12 inch charging section, and hence it will be necessary to mount a blank section immediately above or below such a charging section, so that the rheostat may be assembled behind the switchboard panel.

Assume, for an additional example, a rheostat designed to charge 24 to 26 lead cells only, requiring a charging rate of 30 amperes at the start and 12 amperes at the finish. In this case a distance of only three feet is required from the rear of the panel to the rear of the rheostat frame work; whereas, if the rheostat is designed for 40 to 44 lead cells only, the distance required is but two feet

If an installation involves the charging of a large number of batteries which are identically the same, the selection of the equipment is quite simple. If, however, the batteries to be charged are of various types, capacities and number of cells, the selection of the proper charging equipment becomes more complicated. An individual charging circuit may be provided for each battery, with a rheostat designed for that battery. If there are only a few types of batteries and several batteries of each type and capacity, and if it is not necessary to charge them all at once, a smaller number of rheostats will be required. For public garages, where batteries of unknown capacities are to be charged, the most flexible operation would be obtained by the use of universal rheostats designed for batteries of widely differing numbers of cells and charging rates. The initial cost of the installation, however, will be less if the circuits are provided with various rheostats, each designed for a specific battery.

APPARATUS FOR CONSTANT-POTENTIAL CHARGING

As stated above, the proper potential for charging an Edison battery by the constant-potential method is 1.7 volts per cell; whereas for a lead battery the proper potential is 2.3 volts per cell. If direct-current service of 110 volts is available, an Edison battery comprised of 63 to 66 cells may be charged directly from the line. If the battery is of less than 63 cells, then a rheostat, fixed resistance or a motor-generator set will be required. A lead battery of 48 cells may be charged directly from the line. If the lead battery is of less than 48 cells, then a rheostat, fixed resistance or a motor-generator set may be used; or counter e.m.f. cells may be connected in series with the battery.

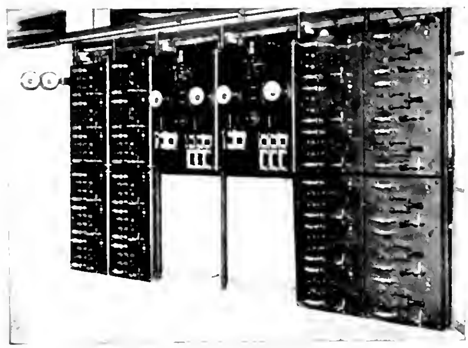

FIG. 8—BATTERY CHARGING BOARD
Of the Stillam-Brown Estate, Toledo, Ohio. This switchboard controls two motor-generator sets of 36 kilowatts each and one set of 1.2 kilowatts. Each of the larger generators is designed for an inherent compounding of 70 to 77 volts, no load to full load, and 125 to 110 volts, no load to full load, obtained by manipulating the shunt field rheostat. Any charging circuit can be switched to either of the two sets of bus-bars receiving power from either of the 36 kilowatt generators, as shown in Fig. 10, thus providing for double-voltage charging. This switchboard and motor-generator equipment incorporate all the advantages of the double-voltage and constant-potential methods of charging. Each rheostat is designed for charging thirty lead cells at rates varying from 40 to 5 amperes based on a potential varying from 120 to 70 volts, and is also arranged to be short-circuited for constant-potential charging at a continuous rate of 100 amperes or a momentary rate of 150 amperes.

The number of counter e.m.f. cells required can be calculated on the basis of 2.3 volts per storage cell, and three volts per counter e.m.f. cell. Thus, a 30 cell lead battery at 2.3 volts per cell has a counter e.m.f of 69 volts, and therefore, for a 110 volt line we have $\frac{110-69}{3} = 13.3$, or 14 counter e.m.f. cells. If alternating-current service only is available, then a motor-generator set must be used, because a rectifier will not have sufficient capacity for charging most batteries by the constant potential method.

To complete the charge of a battery in a minimum length of time it is necessary to hold the charging current constant at the finishing rate for a lead battery, or at the normal rate for an Edison battery after the current has decreased to that rate. A lead battery having been previously discharged will be charging at the finishing rate at the end of about 3.5 hours after having been connected to the constant-potential line. In order to maintain the current at the finishing rate, it is necessary to gradually increase the potential across the battery.

When selecting a motor-generator set and charging switchboard for the constant-potential method, there are a number of points which must be given careful consideration.

1—The number of cells in series, of which each battery is comprised, will determine the generator voltage.

2—The rated capacity in amperes of the batteries, and the sequence or cycle of connecting the batteries to the charging circuits, will determine the ampere capacity of the generator and also the capacity of the apparatus on the switchboard.

3—Is it desirable to charge the batteries in a minimum length of time by raising the potential across each battery when the charging current has decreased to the proper rate?

It will also be necessary to consider the questions in paragraphs (5) to (14), inclusive, given under "Apparatus for Constant Current Charging."

Where it is desirable to raise the voltage of the charging circuits, in order to complete the charging of the batteries in a minimum length of time, it will be necessary to supply a rheostat for each charging circuit, so that the charging current may be held constant at the proper rate after the current through each battery has decreased to this rate. Unless the time available is sufficient and the conditions are such that the same generator can be operated at a higher voltage for finishing the charging of the batteries, then two or more generating units will be required. Part of the generators will be operated at the normal potential and the remainder at the higher voltage required for finishing the charge. Switches, fuses, circuit breakers and meters for the constant-potential method of charging must be of sufficient capacity to carry the large current which will flow into a completely discharged battery.

APPARATUS FOR DOUBLE OR MULTIPLE VOLTAGE CHARGING

Double or multiple voltage charging* is not a distinct method of charging, but is a modification of the other methods. It involves the use of two or more generators operated independently at different voltages. The charging switchboard, in this case, is provided with a common positive or negative bus-bar and an individual negative or positive bus-bar, respectively, for each generator.

To provide the most flexible equipment, each charging circuit should be provided with switches, whereby the battery connected to that circuit may be switched to any one of the generator circuits. There are cases, however, when it is not necessary to provide such switching equipment for each charging circuit, and hence switching equipment is provided whereby all of the charging circuits on a single panel may be switched as a unit to the various generator circuits. The former scheme will result in a minimum loss in the charging rheostats, as the various batteries may be charged on the voltage best suited to their requirements. Such a scheme is particularly desirable when a number of batteries are charged

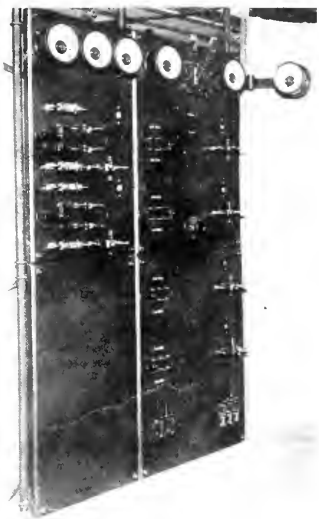

FIG. 9—AUXILIARY BOARD TO THAT SHOWN IN FIG. 8

The left-hand panel is designed so that a battery may be charged from one of the 36 kilowatt generators or so that the battery may be discharged, thus providing for forming and treating new batteries or old batteries which have been refilled with new elements. The right-hand panel is designed for charging and discharging ignition and lighting batteries, power being received from the 1.2 kilowatt generator. Each rheostat is designed for charging two lead cells at rates varying from 20 to 2 amperes on a potential varying from 30 to 20 volts, and so that it may be entirely short-circuited for the constant-potential method of charging at rates of 30 amperes and lower. The batteries may be discharged through the same equipment. All charging circuits in Figs. 8 and 9 are provided with a spring return, single pole, double throw transfer switch with automatic voltage contacts, whereby the charging or discharging voltage of any battery will be indicated when the ammeter switch is thrown to connect the battery ammeter in any battery circuit.

by the constant-potential method and have the charging rate maintained constant at the proper rate, when the current through the battery has decreased to that value. Such a scheme will also reduce to a minimum the number of counter e.m.f. cells required for batteries of small numbers of cells.

*See article by Mr. T. H. Schoepf in the JOURNAL for June, '12, p. 523.

APPARATUS FOR FIXED RESISTANCE CHARGING

This system of charging is usually used only in isolated cases, where but one or two batteries are to be charged without the attention of a skilled attendant. The scheme is used for isolated lighting plant batteries and for boosting batteries on storage battery locomotives where it is desirable to mount the resistance on the locomotive and it is not desirable or practical to have an adjustable rheostat.

The proper fixed resistance to be selected for charging a battery is dependent upon a great many conditions, and the method at best is only a compromise between the constant-current and the constant-potential methods of charging, as it possesses neither the flexibility of the former nor the efficiency of the latter.

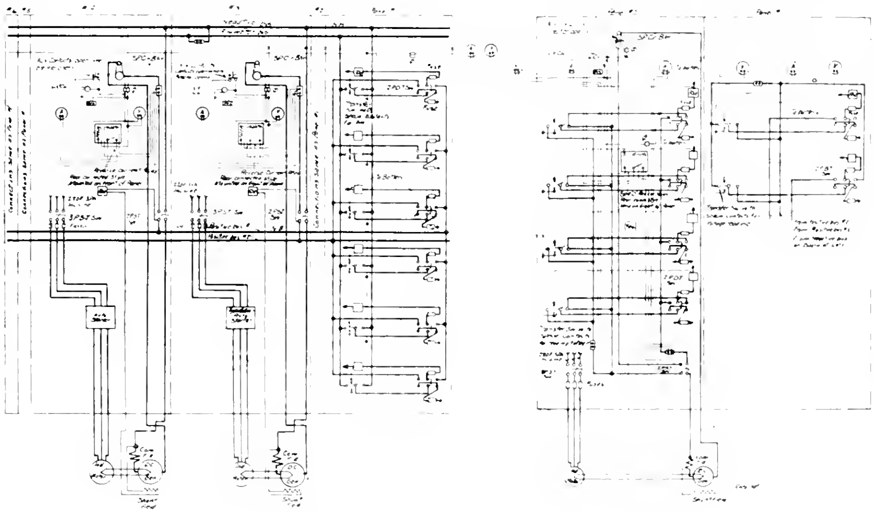

FIG. 10—DIAGRAM OF CONNECTIONS OF BOARDS SHOWN IN FIGS. 8 and 9

A proper fixed resistance for a battery depends upon:—

1—The number of cells to be charged in series
2—The potential of the line
3—The state of discharge of the battery when charged through the fixed resistance.
4—The rate at which the battery is to be charged.
5—The length of time the charge is to be continued.
6—The position and location of the resistance.

This type of charging is used extensively in isolated plants where the battery is broken up into two equal parallel groups of cells for charging. In this case a separate fixed resistance is regularly provided for each half of the battery.

EQUALIZING LEAD BATTERIES

A lead battery of any type must be given an equalizing charge at least once every two weeks regardless of the method used for regular charging. The equalizing charge must be given after a regular charge and should be maintained at a rate not greater than the finishing rate, and preferably at about one-half that value. It should be continued for a period of from two to four hours, or until the specific gravity of the electrolyte has become constant as indicated by three hydrometer readings, taken one-half hour apart. The function of the equalizing charge is to convert that portion of the lead sulphate normally formed by the various discharges, which has not been converted to lead peroxide by the regular charges. Charging installations for lead batteries should include equipment necessary for the equalizing charges.

The potential required for equalizing a lead battery is inversely proportional to the temperature and the age of the battery. At temperatures between 90 and 70 degrees F., it will vary from 2.6 to 2.7 volts per cell.

FORMING AND TREATING BATTERIES

A garage which is properly and completely equipped for repairing as well as for charging batteries will have apparatus whereby both Edison and lead cells may be formed or treated. After new elements are placed in lead or Edison cells, these elements can be gotten into a state of full charge or capacity only by a series of charges and discharges at exceptionally low rates until the cells begin to show capacity. As the capacity is built up, the charging and discharging rates are gradually increased until the cells are in a normal state. Such a process is known as forming or treating. It is evident that each charging circuit, which is also to be used for forming batteries, must be provided with a rheostat designed for charging and discharging a battery, not only at the normal rates, but also at the very low rates required. Additional switching equipment is also required to provide for both the discharging and charging functions. The discharging function may be readily provided for standard battery charging switchboards.

PROTECTIVE AND AUXILIARY METER EQUIPMENT

Circuit Breaker Protection—For large installations it is not customary to provide circuit breakers for over

load protection, except for the main line or generator circuits. However, standard switchboard equipment can be provided with automatic overload circuit breakers for the individual charging circuits. When circuit breakers are provided for the battery circuits it is customary to use a single-pole circuit breaker on the negative side and an enclosed fuse on the positive side of each circuit.

Reverse Current Protection—Protection against reverse current means protecting the equipment against the possibility of the batteries discharging back into the system when the power supply fails or decreases below normal. Such protection is particularly desirable for installations wherein compound-wound generators are used for charging, because the reversal of current may cause the generator to rotate at abnormally high speed and ultimately reverse in polarity and possibly flash over. If shunt-wound generators are used, the reversal of current will do no immediate damage, but the batteries will be discharged.

To protect against reversal of current it is natural to assume that a circuit breaker equipped with a reverse current release mechanism would be the proper application, but such is not the case,* unless the functioning of the mechanism is practically independent of line potential variations. The usual reverse-current release consists of an electromagnet having two differentially connected windings, one of which is connected across the line, while the other is connected in series with the circuit to be protected. When full potential is applied, a small reverse current will trip the circuit breaker. But with only 60 to 80 volts across the line, such as would be developed by the battery during a failure of power supply, a much larger reverse current would be required to actuate the reverse-current device, and hence the conversion may be reversed without tripping the circuit breaker. For this reason an under-voltage release mechanism is usually used for protection against reverse current, as it will, if correctly adjusted, function properly in all cases, because the discharge voltage is always less than that required to charge a battery.

To provide the most effective and flexible protection against reversal of current, each individual charging circuit should be equipped with a low-voltage release circuit breaker, or a circuit breaker and a sensitive reverse-current relay or mechanism. The next best protection is secured by providing this equipment in the main line or generator circuit only. This latter scheme will effectively protect the generating equipment, but after the circuit breaker opens the batteries will remain connected in parallel to the bus-bars, and hence the batteries developing the highest e.m.f. will discharge into the others. Furthermore, if the low-voltage release circuit breaker only is provided, it will be impossible to operate the generator at a potential lower than the setting of the low-voltage mechanism attached to the generator circuit breaker, or the circuit breaker in any charging circuit which is in use.

*See article by Mr. H. E. Trent in the JOURNAL for Aug., '15, p. 360.

Automatic Termination of Battery Charging—There are many installations wherein it is desirable that the charging of a battery be terminated automatically when it is completed. The majority of mechanisms for this purpose depend upon the rise in counter e.m.f. of a battery to operate relays; such a scheme is unreliable and is almost certain to result in either undercharging or overcharging the battery. Furthermore, this type of mechanism is not applicable for constant-potential charging installations. The counter e.m.f. of a battery becomes practically constant during the last half hour of the charging period, and a mechanism dependent upon the voltage must not only be very sensitive, but to insure its action should be set to disconnect the battery before it is completely charged. The final charging voltage of a battery also varies with the temperature

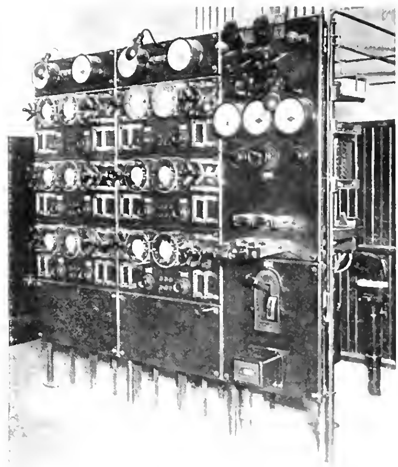

FIG. 11—BATTERY CHARGING PANELS

Of the Curtis Publishing Company, Philadelphia, Pa. This board controls a 75 kilowatt motor-generator set. Each rheostat in each of the twelve battery charging circuits is designed to charge a 45 cell lead battery at 50 amperes start, 24 amperes finish; also to charge a 45 cell lead battery at 50 amperes start and 21 amperes finish; also to charge a 60 cell Edison battery at 30 and 60 amperes; also to charge a 60 cell Edison battery at 45 and 90 amperes. The generator is protected against reverse current by means of a reverse current relay. Each battery charging circuit is provided with a watthour meter; a totalizing watthour meter is provided in the alternating-current motor circuit, and a similar meter in the direct-current generator circuit.

and the age of the battery, and therefore, a mechanism dependent upon the voltage will require adjustment from time to time, which at best would not assure the proper functioning of the mechanism, because conditions might easily change soon after the adjustment is made.

The only equipment which can be depended upon to properly and unfailingly perform this function is the combination of an ampere-hour meter equipped with a zero contact and reset device, and a circuit breaker provided with a shunt trip or a low-voltage release mechanism and a small resistance. This equipment must be connected in the battery circuit, so that when the battery is

charging the pointer of the ampere-hour meter will be moved back toward the zero position at which the zero contact is located. When the pointer touches the zero contact a circuit is established whereby the circuit breaker is tripped. The small resistance limits the flow of current when the coil is short-circuited.

In a great many instances the ampere-hour meter and a shunt-trip circuit breaker are mounted directly on

FIG. 12—STARTING EQUIPMENT AND MOTOR-GENERATORS OF THE CURTIS PUBLISHING COMPANY

the vehicle, and hence no such equipment is required on the switchboard. In other instances there is an ampere-hour meter, but no circuit breaker, on the vehicle, and it is then necessary to mount a low-voltage release circuit breaker on the switchboard. It is also necessary to supply a small auxiliary plug and receptacle of sufficient capacity to carry about 25 amperes; the receptacle to be mounted on the vehicle and connected to the zero contact of the ampere-hour meter, the plug being connected by means of a suitable cable to the low-voltage release coil on the switchboard, so that the circuit breaker will be tripped when the pointer of the ampere-hour meter touches the zero contact. Where no ampere-hour meter is available on the vehicle a low-voltage release circuit breaker and ampere-hour meter are provided on the switchboard for each charging circuit.

The ampere-hour meters used for this class of service should be either of the differential shunt type or the variable resistor type. One of these meters properly and permanently connected in a battery circuit will, within a reasonable degree of accuracy, indicate at all times the ampere-hour capacity out of the battery. When the battery is completely charged, the pointer of the meter is at zero; as the battery is discharged, the meter pointer moves away from the zero position, and when it indicates that the rated capacity of the battery has been taken out, the battery must be charged. It is during the charging period that the unique characteristics of the ampere-hour meter are evidenced, for when the charging current flows into the battery the meter pointer moves back toward the zero position, but at a lower speed relative to the speed per ampere-hour when the battery is being discharged. As a result, more ampere-hours are put back into the battery on charge than are taken out on discharge, thus compensating for the efficiency of the battery, which is always less than unity. The ampere-hour efficiency of a lead battery differs from that of an Edison battery, and hence these meters are provided with an adjustment, by means of which each meter may be made to run from 10 to 25 percent slow during the charging period. When an ampere-hour meter is used with a lead battery it is necessary to keep the meter in step with the battery, and hence after each equalizing charge (given about every two weeks) the meter pointer should be set at the zero position.

If the ampere-hour meter which is to be used for terminating the charge of a battery mounted on a vehicle is mounted on a charging switchboard, and the battery has not been discharged through this meter circuit, before beginning the charge the meter pointer must be set at the reading corresponding to condition of the battery and adjusted to run the proper percent slow.

Automatic Termination of Battery Charging and Automatic Disconnecting of a Motor-Generator Outfit—Where a number of batteries are to be charged by means of one or more motor-generator sets, it may be desirable not only to provide equipment whereby the charging of each battery will be automatically terminated after the required charge, but also equipment whereby the motor-generator outfits will be automatically disconnected from the source of supply when the last battery is automatically disconnected from the generator circuit. This latter function may be accomplished by providing an underload release circuit breaker, with auxiliary contacts, for each generator circuit, so that when it opens the motor starter will be moved to the off position. If each battery circuit is protected against

FIG. 13—GARAGE AND CHARGING BOARD

Of the West Penn Auto Company, Pittsburgh, Pa. A 15 kilowatt motor-generator set supplies 125 to 60 volts to six battery charging circuits. The rheostats are designed for charging 40 lead cells at 28 amperes start and 12 amperes finish, and also 24 lead cells at 30 amperes start and 6 amperes finish.

reverse current, and the motor circuit is protected against low-voltage and overloads, then the installation is completely protected against total or partial failure of the power supply.

Watthour Meters—For some installations it may be desirable to provide an individual watthour meter in each battery-charging circuit, either to assist in keeping account of the cost of operation or to provide a means

whereby a direct charge may be made to each customer on the basis of the actual power required for charging the various batteries. To meet this requirement a switchboard type watthour meter equipped with a large circular dial and pointer in addition to the standard train of four integrating dials is provided. The large dial is calibrated for a limited number of kw-hrs., and the pointer may be turned to zero at any time by means of a knurled nut mounted on the front of the glass case. Or if desired, the meter can be so equipped that the pointer can be turned with a square shanked key only, thus assuring that only authorized parties will be able to reset the meter. The totalizing dials indicate the total power passing over the metered circuit; whereas the large dial indicates the power consumed for each charging period, after which the pointer should be reset to zero.

Special Equipment—There are numerous additional functions which can be provided for standard battery-charging switchboards, among which are a pilot or indicating lamp for each charging circuit and a spring return ammeter switch, which may be provided with an automatic voltmeter contact for each charging circuit. Watthour meters may also be supplied to totalize the power delivered by a generator and also the power required from the line by the motor driving the generator. Any of these meters may be of the indicating type or of the graphic or recording type.

The Mercury Arc Rectifier

FOR CHARGING ELECTRICAL VEHICLE BATTERIES

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For charging the batteries of single electric vehicles there is no superior to the mercury arc rectifier. This holds not only in the case of the battery that is to be charged without attendance in the private garage, but also in those cases where, even in a large public garage, it is necessary to charge a battery of an unusual number of cells, or during the peak load hours, when extra rates are charged for current by the power company. The reasons for this superiority are numerous. Not only is a rectifier more efficient than any other charging device, but it requires less floor space. Its operating and first costs are lower and its installation is simplicity itself. It is noiseless and free from dirt, oil or moving parts. It can be adjusted in a moment to suit the line voltage and number of cells and gives the battery in all cases the tapering charge so desirable with a lead battery.

FIG. 1—30 AMPERE RECTIFIER BULB FOR BATTERY CHARGING

The heart of the mercury rectifier is the bulb which changes the alternating current into slightly pulsating direct current. A 30 ampere bulb of the sort commonly used for vehicle battery charging is shown in Fig. 1. In order that they may give the best possible operation, these bulbs are pumped off to the highest possible degree of vacuum and every care is taken to drive off all the gases and water vapor that may be imprisoned in the materials of the electrodes or the walls of the tube. This is accomplished by heating the bulb in an oven until the mercury boils, and also heating the electrodes to a white heat, by passing current through the bulb while the pumps are still in operation. The rectifying power of the bulb is derived from the fact that the mercury vapor will only maintain an arc in the direction toward the mercury, i. e., with the mercury pool as a cathode. If only one anode was provided, therefore, the arc would go out at the end of the first half cycle of the alternating-current wave. For that reason, two anodes are provided which both deliver current to the same mercury cathode. These anodes are so connected to the circuit that they work alternatingly—one delivering current during one half wave and the other during the second half wave, the hollow between the two half waves being filled in by energy stored during the peak of each half wave in an inductance in the direct-current circuit. This gives not only a rectified current, but a fairly smooth direct current. This sustaining inductance, as it is called, may take the form of a coil connected in the direct-current circuit, or more usually, it is made a part of the transformer itself.

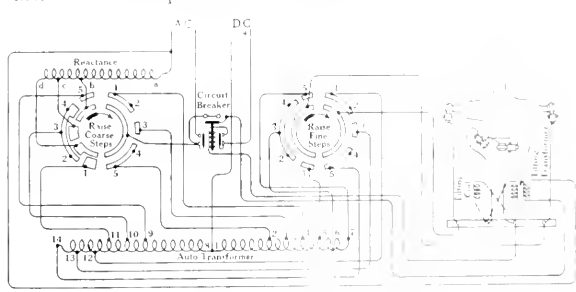

FIG. 2—WIRING DIAGRAM OF SELF-STARTING, 30 AMPERE RECTIFIER FOR 110 VOLTS ALTERNATING CURRENT, AND 20 TO 44 CELLS OF LEAD BATTERY

A schematic diagram of a mercury arc rectifier circuit is given in Fig. 2. The transformer serves to change the line voltage to the value best suited to the

battery to be charged. The two anodes of the bulb, usually made of graphite, take current during alternate half waves from opposite ends of the transformer secondary and deliver it to the mercury cathode, whence it flows as direct current through the battery back to the middle point of the transformer.

To start a mercury rectifier bulb, it is necessary to cause a spark at the surface of the mercury. The simplest way is to provide a small starting resistance, which is connected between one anode and the second mercury pool. When the bulb is tilted so that the mercury pools come together, alternating current will flow through the resistance and the mercury. When the bulb is then tilted back so as to separate the mercury pools, the current is interrupted and a spark occurs between them. If the direction of the current happens to be such as to make the main mercury pool negative, the load current will start to flow from whichever anode is positive at the time. If not, the bulb will have to be tilted again. When a bulb is very cold it is harder to start, since it then contains very little mercury vapor, as most of the latter has condensed. Starting can be made easy again by warming the bulb up to ordinary room temperature.

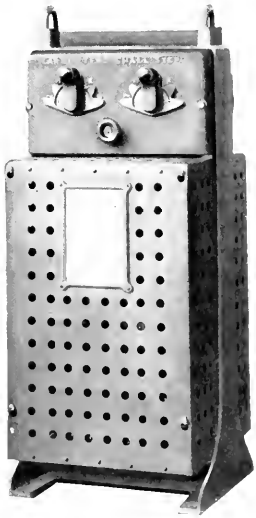

FIG. 3 30 AMPERE RECTIFIER FOR CHARGING LEAD CELLS

To control the current and adjust the rectifier to different line voltages and different numbers of cells, taps are usually provided on the transformer for changing the connections to the bulb or the alternating-current line. In this way adjustments can be made efficiently and without the losses that would result from the use of a resistance. One advantage of the rectifier is that all adjustments can be made by transformer taps.

For charging lead storage batteries, it is important that the current should decrease as the charge progresses, inasmuch as toward the end of charge only a small amount of current can be utilized in chemical action and any additional current would simply be wasted in heat and the battery very probably injured by overheating. For this reason it is important that rectifiers for charging lead batteries should be so designed that the charging current automatically tapers off a proper amount as the charge progresses, without attention on the part of the operator. This is usually accomplished by connecting a reactance coil, as shown in Fig. 2, in series with the alternating-current line and so proportioning it with respect to the transformer taps that the right tapering of charging current is obtained, no matter what transformer connections are used. This same result can also be accomplished without the use of a separate coil by a special design of the transformer.

A standard type of 30 ampere mercury rectifier for charging from 20 to 44 lead storage cells, which embodies the features outlined above, is shown in Fig. 3. An upright main cast iron frame has mounted on its back the alternating-current reactance coil and the transformer. In front of the transformer is the bulb, while at the top of the outfit is a slate panel carrying dial switches, by means of which the transformer connections can be easily changed for adjusting the current. These switches are so designed that they can be manipulated without putting out the arc in the bulb. The transformer, reactance, bulb, dial switches and all other live parts are enclosed in perforated iron covers, thus entirely protecting both the operator and the apparatus. The upright construction takes up a minimum of floor space, and the design of the outfit as a self-contained unit reduces the difficulties of installation to a minimum, since it is only necessary to connect to the outfit the two wires from the alternating-current circuit and the charging cable to the vehicle. Sustaining is accomplished by special design of the transformer, without the use of a separate reactance coil.

Outfits such as shown in Fig. 3 are furnished for automatic starting, as well as for hand starting. The automatic starting is accomplished by a specially designed tilting magnet, which tilts the bulb as soon as the line switch is closed, and continues to do so until the main arc starts up. As soon as this occurs the magnet is cut out of service by a special relay. If the arc goes out for any reason the relay connects the magnet back in circuit again and the bulb is again tilted till the charging arc starts. This automatic restarting feature is a very great convenience where a rectifier is used in a private garage for unattended night charging, inasmuch as without it a single interruption of the arc from any cause would stop the outfit and leave the battery without the expected charge.

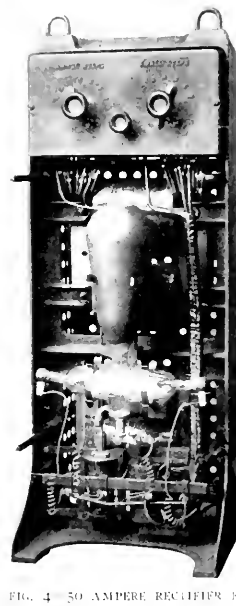

FIG. 4 50 AMPERE RECTIFIER FOR CHARGING EDISON CELLS

Where Edison batteries are to be charged, larger outfits are usually required than that above described. A 50 ampere outfit for this service is shown in Fig. 4.

In general, the design is the same as described above, but the reactance is designed to give a much more nearly constant current throughout the charge, as is recommended for Edison cells. This outfit, by means of its dial switches provides 49 different points of adjustment, as compared with 25 available on the 30 ampere outfit.

In recent years there has been, at least in the automobile field, a steadily increasing popular demand for cheaper and simpler designs. This is exemplified in the great increase in the sale of low-priced gasoline cars, and is this year becoming evident also in the reduced prices for electric vehicles. In line with this general trend, it has been necessary to produce simpler and lower priced rectifiers as well. Every effort has been made, however, to retain the rectifier's fundamental advantages of high efficiency, simplicity of installation and operation, small size and freedom from noise and dirt. A 30 ampere rectifier of this recent simplified type and lower cost is shown in Fig. 5. As in the more elaborate design, first described, all parts are mounted on a single cast iron frame, which encloses the outfit and protects the bulb on the front. Every effort has been made to reduce the cost of this outfit by eliminating all features that were in the nature of refinements and were not necessary to the proper operation of the outfit. Simplicity has been carried to the limit by doing away not only with the separate sustaining coil, but with the separate reactance as well. A novel design has made it possible to incorporate both the reactance and sustaining features in the transformer, and thus only one coil is now required where in the earlier designs as many as three were used for the same service.

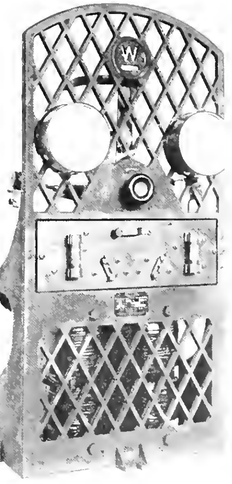

FIG. 5—SIMPLIFIED TYPE OF RECTIFIER

This outfit is designed for charging from 38 to 40 lead cells, or 56 to 66 Edison cells, which covers the range of battery sizes commonly used on electric vehicles. A small slate panel on the front of the outfit is provided with link connections to taps on the transformer, whereby the outfit can be adjusted to suit the line voltage and number of cells to be charged. As this connection is rarely changed after installation, the elimination of the expensive dial switches causes little, if any, inconvenience. Like the more expensive outfits first described, this rectifier is so designed that it will deliver current to the battery at a rate depending on how far the battery has been discharged—provided, of course, that the proper link connections are used. If the battery is fully discharged, the rectifier will deliver its full rated current. To a partially discharged battery it will deliver, say, two-thirds of its rated current, while to a fully charged battery it will deliver only one quarter to one-third of its rated current.

For the electrical vehicle owner, who by choice or necessity charges his battery at home, the mercury rectifier is the best charging device that is available. It takes a minimum of floor space and, since it has no moving parts, needs no oiling or other attention except to start it up and stop it. Because of its high efficiency, its operating cost is exceptionally low, while the initial and installation costs are far below those of any other device for the same service. A recent improvement has been made in the impregnation of the transformer coils which eliminates practically all the humming sound characteristic of any transformer and renders the rectifier so noiseless that it will be particularly satisfactory when it is necessary to install it near the sleeping quarters of the owner or his chauffeur.

The rectifier is useful not only in the private garage, but it is also a valuable adjunct to a large public garage, where so many cars are charged at a time that a large motor-generator set is required. In a large garage of this sort there will be frequent times when it is more economical to use one or two rectifiers than to use the large motor-generator set. For instance, it is often possible to obtain a lower rate for current if it is agreed not to run the large motor-generator set during certain hours of the day. It will, however, often be necessary to charge one or two cars during that period. Likewise, during regular charging hours, there will often be one or two cars that have batteries of unusual number of cells. To charge these from the motor-generator at the same time as the other batteries would involve the use of wasteful resistance in series either with these batteries or the larger number of standard batteries. In either of these cases, one or two rectifiers could be used to advantage to take care of these special batteries or to charge during hours when the motor-generator set was not operating.

There is, therefore, a large field for the use of mercury arc rectifiers for charging electrical vehicle batteries, both in the private garage and in the larger public garages, and the increasing use of electric vehicles, together with the development of improved rectifiers of lower cost, should lead to their much wider use.

Small Motor-Generator Sets

FOR CHARGING STARTING, LIGHTING AND IGNITION BATTERIES

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Low voltage storage batteries have been used to a limited extent for lighting and ignition service on passenger gasoline cars for approximately eight years, and for starting service approximately five years, but it is only within the last three years that they have come into almost universal use.

Direct current is necessary for charging storage batteries, but the zones where direct current is available are more or less limited, the commercial circuits being mostly alternating current. Where direct current is available, the commercial voltage is either 115 or 230 volts, so that unless a large number of low-voltage batteries are to be handled, it is necessary to reduce the voltage to the proper value by means of a resistance which makes charging uneconomical. Where alternating current is available, some means must be provided for changing the alternating current to direct current.

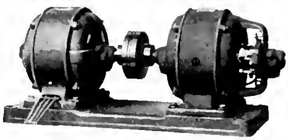

FIG. 1—ALTERNATING-CURRENT MOTOR DRIVING LOW-VOLTAGE DIRECT-CURRENT GENERATOR

Charging the batteries and renewing of plates is done on a large scale by battery service stations. The general garage must, however, be equipped to render service in the way of charging and must have some economical means of changing either the alternating-current supply or the commercial direct-current supply service to direct current of proper voltage to meet the requirements. Small motor-generator sets with control panels have been placed on the market for this service.

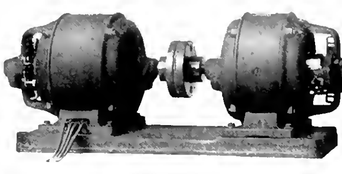

FIG. 2—DIRECT-CURRENT MOTOR DRIVING LOW-VOLTAGE DIRECT-CURRENT GENERATOR

Battery manufacturers would prefer that batteries be charged separately or in multiple, each circuit being controlled by an individual charging resistance. Such an arrangement would mean a generator of high ampere and low voltage characteristics and a special control system, both of which would be expensive, and the investment of capital to obtain this would hardly be favorably considered by the general garage. The cheapest proposition consists of a motor-generator set with control panels for charging batteries in series, in which case a generator of low current and medium voltage can be used with a simple control panel, a scheme which is very desirable from the investment point of view. The Underwriters' requirements on electrical equipment for garage service are very stringent. Motor-generator sets must conform to these requirements and control apparatus must give ample protection.

In the selection of a motor-generator set of the proper capacity, the characteristics of the supply circuit, the maximum and minimum charging rates, the voltage of the batteries, and the number of batteries to be charged in series at one time, must be taken into consideration. The current rating depends on the maximum and minimum charge rate. The charge rates as recommended by battery manufacturers average from fourteen to eight amperes maximum, and from five to three amperes minimum, respectively. The average length of time required for a complete charge varies from eight to twelve hours. The voltage rating depends upon the number of cells per battery and the number of batteries to be charged in series at one time. The number of lead cells per battery generally used in this service is three, six, nine and twelve, which give an average discharge potential of two volts per cell and require an average charging potential varying from 2 to 2.7 volts per cell. The charging voltage per battery and the number of batteries to be charged at one time being known, the voltage of the direct-current supply circuit is determined. It should be noted, however, that a battery will not only be injured if charged at too high a rate, but will also lose capacity if charged at too low a rate.

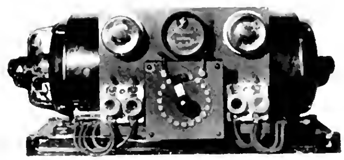

FIG. 3—SELF-CONTAINED MOTOR-GENERATOR SET AND CHARGING PANEL

A lead battery must be given an equalizing or gassing charge at least once every two weeks regardless of the method of charging. The equalizing charge must be given after the regular charge has been completed, and should be maintained at a rate not to exceed the finishing charge rate, and preferably at one-half that value. The equalizing charge should be continued for a period

of from two to four hours, or until the specific gravity of the electrolyte has reached a constant value. The purpose of the equalizing charge is to clear the plates of sulphate, which collects when the battery discharges. In giving an equalizing charge, care should also be taken that the temperature of the electrolyte does not exceed 110 degrees F.

There is a demand for small motor-generator sets for charging batteries on gasoline cars, even though there is a generator installed as a part of each starting, lighting and ignition system, because there are times when the battery becomes discharged when the car is left standing at the curb for extended periods with the lights burning. Furthermore, cars are often stored for long periods during the winter months, during which time the battery should be given a periodic charge to clear the plates of the sulphate which accumulates when the battery is not used.

One-Unit Starting and Lighting Automobile Equipments

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SINCE electricity was first used as a means of starting and lighting in connection with gasoline engines on automobiles, motor-generators (starter and lighter in one unit) have been employed more or less extensively. The rapid development and continual evolution along all branches of the automobile industry has naturally had an effect on the use of the motor-generator. For instance, the cars manufactured by any one company for a particular year on which the single unit made a very good application might be so changed the following year that the single unit would be very unsatisfactory. Although the general tendency seems to have been toward the use of two units, motor and generator, the ideas and policies of some automobile engineers combined with those of electrical outfitters in some instances have tended toward the use of one unit; hence certain makes of automobiles have been put on the market year after year for which motor-generators do the cranking and battery charging.

MANY types of motor-generators have been placed on the market, some of which might be termed freak designs, while others, although having many unique features, follow standard and reliable practice. These units operate with batteries of different voltages, 6, 12 and 24 volts being used. Some use one voltage for starting and charge the battery at another as 12 and 6 or 24 and 6 by connecting the battery cells in series and in parallel. These two-voltage systems necessarily require a fairly complicated set of relays and switching mechanisms, to say nothing of special battery connections. There are also in use what might be named two-speed motor-generators, i. e., the ratio of drive between gas engine and electrical unit is not the same when operating as a motor as when being driven as a generator. Systems of this kind are propelled and obtain their motor and generator ratios by means of sets of gears and overrunning clutches. Another type of single unit is the machine with a double winding in the armature core, each with its own separate commutator. One winding is made up of a few conductors of large and low-resistance wire for carrying the large starting current, the other being composed of many more turns of smaller wire for generating the battery charging current. The flywheel motor-generator is also fairly well known. Herein the rotor of the unit replaces the flywheel and must perform all the flywheel duties in addition to its own. The materials—copper, insulation, special iron, etc.—used in the flywheel type rotor are much more expensive than in the conventional flywheel, and the more complicated construction represents quite an additional expense for manufacture. It is a fact that the diameter and length of the rotating parts of the electrical motors and generators should bear certain relations to each other in order to obtain economical designs. An exceptionally long armature core of small diameter or, as is the case with the flywheel motor-generator, a short core of large diameter, is badly proportioned and is expensive to manufacture. The different types of machines mentioned above are, as a rule, satisfactory in operation, but are more expensive to buy and install on account of their necessary accessories, such as switches, clutches, etc. There are also in use motor-generators which are driven as generators by belts over pulleys of low ratio and drive the engine by high ratio gears meshing with a gear ring on the flywheel. The starting gears are demeshed by a manually operated pinion. During the cranking period the belt is supposed to slip the amount of difference in ratios.

The simplest type of motor-generator known to the writer has one armature winding and commutator only, and operates both as a motor and generator without stepping the voltage up or down by parallel and series connections. Also, the ratio of drive between the dynamo and engine is the same at all times. This unit is so designed that it may be used without even an automatic battery cutout of any description. The current regulation is cared for inherently by means of a third brush for controlling the shunt field circuit and a differentially compounding field. The automatic battery regulator may be applied conveniently, if desirable, in place of the above means of regulation. When applied

on very light engines of low throttling characteristics a simple reverse current relay switch may be used, if desired, to open the motor and battery circuit and thus prevent the engine from floating on the motor when running idle.

The performance characteristics of the motor-generator are usually shown divided, i. e., the motor curves and generator curves are separated, although the latter should be a continuation of the first. Usual practice gives the torque, r.p.m., etc., of the motor with relation to amperes taken from the battery, and the generator regulation with relation to armature revolutions per minute. For convenience, the curve in Fig. 1 gives the performance both as motor and as generator with regard to speed. In the illustration the scales for amperes and r.p.m. have been given different values for motor and generator to facilitate the curve study, the point of change being where the machine passes from a state of motoring to generating; in this case 900 r.p.m. This is also called the balance point, since the machine is just balancing the open circuit voltage, which is about 13

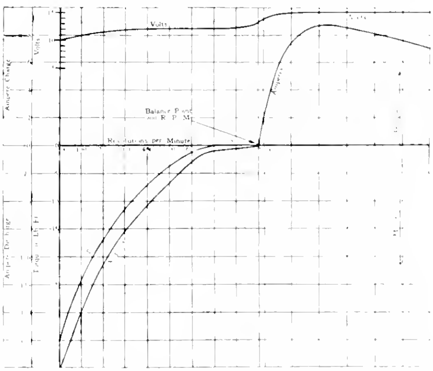


FIG. 1—APPROXIMATE PERFORMANCE OF A MOTOR-GENERATOR FOR AUTOMOBILE STARTING AND LIGHTING
Machine at room temperature

volts at the terminals of a six-cell battery, and there is neither a charging nor discharging current.

Consider first the performance as a motor. When the starting switch is closed with the engine at rest (zero revolutions) a large starting torque is produced. The voltage curve shows the characteristic dropping voltage of the ordinary storage battery under heavy current demands. As the engine is brought up to speed the torque and current rapidly decrease until the motor is supplying its maximum power, which should be at the normal cranking speed.

The engine, having started, now increases the motor-generator speed until the balance point is passed and the machine as a generator begins charging the battery. The application should be so made that the balance speed will be approximately nine miles per hour, depending on the gear reductions and rear wheel diameter. After passing the balance speed the charging current increases rapidly as the car speed increases, until a maximum value is reached which is within the safe operating conditions for the battery. A further increase in speed shows the output and consequent necessary power demand from the engine slightly decreasing. This occurs at a time when the engine requires its power for greater car speed, and is consequently a favorable asset in the machine. As previously stated, a battery cutout or simple reverse current relay switch may be so connected in the circuit that as the generator speed drops below the balance point the small discharging current opens the switch and the motor-generator is completely disconnected from the battery, the motor connections being open when the starting switch is released. By this means a large discharge current is prevented from passing through the machine. When the speed again passes above the balance point the cutout switch will close automatically and again connect the generator with the battery.

The field of application of the motor-generator is governed by many things, most of which are matters of economy and engineering judgment. In so far as the machine satisfies the demands required as a starting motor alone or as a generator alone in regard to operation, it may be placed competitively against the separate units. The economy of its use depends on the cost of equipment, cost of application, cost of maintainance and engine power demand. In order to compete successfully with other equipments the manufacturer must be able to build and sell at a price approximately the same as for the two units. Not by the machine alone, but by the complete outfit with its switches, relays, clutches, gears, chains, battery, etc., is the price determined. The simpler types of single-unit application, as already described, require very few of the above accessories and, although the motor-generator will be considerably larger and more expensive than either of the single units, the price competition may sometimes be successfully met. The extremely different current and speed characteristics of starting and charging make it necessary to greatly increase the size of the machine employed for both. The starting motor must carry a large current at low voltage. In order to do this it must have heavy copper conductors of low resistance in its field coils and armature at the sacrifice of the number of conductors. The capacity of the motor at starting is usually about one horse-power (746 watts), while the capacity of the generator is approximately 100 watts. To maintain this continuous 100 watt output it is necessary to have many more turns in the armature and field for generating the necessary voltage than is required by the motor. Possibly a very few turns could be added to each armature coil by increasing the size of the armature, but the greater part should be added to the field coil. To accomplish this a shunt coil of small wire and many turns is placed on each pole.

Assuming that a motor-generator with a complete equipment may be obtained for a certain price, the competition is then narrowed to a matter of mechanical application. It is for the engineer to decide on the type of drive, viz., chain, gears or belt, from which end of the engine it is to be driven and the location of the

unit. Sometimes the automobile is so constructed that there is no choice in regard to these points. For instance, there might be only one location for the machine and one means of drive. The available space under the hood is often very limited. Such being the case we have a field of application where the demand is a minimum of parts, a minimum of space and a maximum of compactness. Perhaps the best known example is the Ford Model T engine, for which there are so many equipments of different makes. At the present time there are no systems other than the single unit used extensively on this car, for it has been found practically impossible to apply a separate motor and generator economically. It must be remembered in this connection that all the Ford applications are made through agents in the field and not at the factory, therefore the parts must fit on the engine easily and without expensive engine alterations.

Serious limitations are encountered by engineers who are in favor of the use of the single unit. Considering first the separate starting motor, we find gear reductions between armature and crank shaft ranging anywhere from 9 : 1 to 30 : 1. With these ratios correctly applied to a motor with a given speed rating the desirable cranking speed for the engine is obtained. The maximum ratio used for separate generators is probably 3 : 1, determined by the safe peripheral speed of the generator armature. Another factor bearing on the limit of the maximum ratio is that generators for automobile use are naturally made as small as possible within reliable engineering practice. Since the size of a generator for a given capacity is nearly inversely proportional to its rated speed, an increase in ratio between engine and armature will allow a smaller generator to be used. There is a minimum limit for the size, however, from a mechanical standpoint, since the size of shaft, amount of insulation, thickness of armature teeth, etc., must not be cut below certain dimensions. Considering the single ratio motor-generator, assume that the ratio of drive is 3 : 1. If this is to have about the same capacity as desired in the separate motor, with a 9 : 1 ratio, its size must be increased approximately in the ratio of 9 : 3, since its speed has been decreased to one-third of the value required for the same capacity. This three times larger armature running at three times crank shaft speed must be designed to stand as high as 6000 to 8000 r.p.m. with a factor of safety. Such a heavy rotor causes a great many severe strains on the driving parts because of inertia against pre-ignition, back-firing and propeller shaft torsion. Since it is impossible to obtain a ratio as low as 3 : 1 by driving from the flywheel, the link must be made through sprockets and chains placed in front of the flywheel or at the cranking end of the engine. Other problems are driving couplings, bearings and balancing against vibration due to the high operating speeds. The engine mounting for the motor-generator is found to be no inconsiderable detail of application. With such a comparatively massive armature rotating at speeds as high as 8000 r.p.m., it is very essential to have a rigid support and perfect shaft alignment, otherwise the vibration would soon do damage to both motor-generator and engine.

Perhaps the greatest problem of any in connection with the single unit is the question of drive. Because of its double function, its heavy rotating parts and great range of speed, all the problems of the two units seem to be combined for the one. In the first place, the driving parts must be strong and heavy enough to transmit the starting torque and yet not give excessive noise, wear and vibration at high speeds. Next, the bearings and mounting must be designed for the same results. The best known types of drive are the "silent" and "link belt" chain, running over pinions and sprockets. Usually with chain drive the main sprocket is placed on the crank shaft at the front end of the engine.

The chain drive, since it has its own special field of application and troubles more difficult to compensate for than gears, will not be discussed in this paper.

The relative simplicity of the motor-generator compares favorably with other types of equipment in so far as its operation is concerned. It may be made to lose some of its advantage in this regard, however, by the addition of features such as voltage regulators, relays, etc., which are considered necessary with the smaller units. When voltage changing devices or gears are used to reduce the bulk of the main part of the apparatus, the simplicity of the equipment as a whole must necessarily suffer.

In regard to reliability, there should be average satisfaction. However, there might be an objection against having all the electrical power plant in one unit. If the machine failed, then both starting and battery charging would probably be eliminated, whereas with two units the failure of one would not necessarily disable the other.

The points governing the selection of the single unit may be summed up briefly as follows:—In the first place, there is one definite field where the unit has no competition, i. e., where the available space is limited. Wherever it is desirable to concentrate the electrical power plant and eliminate all possible parts the motor generator should be used. In other words, there are cases where the application demands a minimum of space, a minimum of parts and a maximum of compactness. On the other hand, it may be either desirable, or undesirable perhaps, to concentrate the entire weight of the outfit at one point. There is still a demand for the motor-generator, and it is quite extensively used at the present day. It is still a factor in competitive application, and its future will depend a great deal on the trend of future automobile construction.

Storing and Releasing Energy

SOME MECHANICAL ANALOGIES TO BATTERY IGNITION

R. P. Jackson

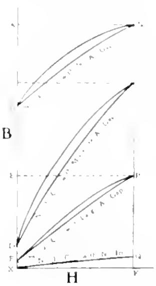
FOR ages man has employed the expedient of storing energy at a comparatively slow rate and releasing it suddenly to accomplish results beyond the resources at his immediate command. The first time he failed to crack a nut between his teeth, but succeeded by laying it on one stone and hitting it with another, he began consciously to intensify the strength he has available by storing it in some external medium from which it could be released suddenly to accomplish his purpose. The bow and arrow followed the club or stone missiles, and he then made use of the two great mechanical storing devices, mass-velocity and spring-deflection. In more modern times, when he learned the use of electricity, similar methods of storing energy for sudden release by means of an electrostatic capacity or an electromagnetic field furnished facilities for doing otherwise difficult tasks. The charging of a condenser is, of course, quite similar to the deflecting of a spring, while the creation of a magnetic field bears a strong resemblance to the acceleration of a mass to a velocity. Probably the mechanical spring device that mathematically most nearly resembles the electric condenser is an air chamber into which more air can be forced by increasing pressure. So long as the air remains a gas and the compression is isothermal, the amount of air Q is proportional to the pressure P and the energy stored is proportional to P^2.

The following are the ordinary expressions denoting the amount of energy stored in each of the four mediums, mass, spring, magnetic inductance and electrostatic capacity :—

$$Energy = \frac{M\ V^2}{2} = \frac{Q\ P^2}{2} = \frac{L\ I^2}{2} = \frac{C\ E^2}{2}$$

In each case there is an element or factor that is essentially material and static, and a factor that represents the kinetic or active energy supplying element. We are accustomed to recognize that, by themselves alone, there is no energy stored in either a mass, a spring or a condenser, without the active element of velocity, pressure or electromotive force. There is a common impression, however, that the stored energy of a magnetic field is due to the lines of force, irrespective of the value of the current that produces it. An examination of the expression for the energy of a magnetic field $W = \frac{L\ I^2}{2}$ discloses that an inductance L of however great value would not store energy if the lines of magnetic force could be produced with zero current. In fact, in some respects a magnetic field also resembles a spring, particularly if the reluctance is in an air-gap. Lines of force in air resemble rubber bands that tend to shorten, collapse and disappear, losing their energy if the coercive force, i. e., ampere-turns, maintaining them is removed. It is true, of course, that the presence of iron in a magnetic circuit increases the inductance L, and so the stored energy per ampere of current in the coils. Reduction of the air-gap and increase of the percentage of iron in the circuit increases the stored energy. There is no gain in released energy from this stored energy, however, when the air-gap has become too small to suppress the flux when the current has stopped. Typical variations of flux and returned energy with various proportions of iron from 0 to 100 percent in a given coil are illustrated in Fig. 1. The greatest release of energy is obtained with an air-gap which gives the widest range C to D from the maximum to the residual fluxes.

For some purposes, such as ignition for example, where a very sudden release of energy is required, it may not even be desirable to use an air-gap so small as this, because of the slowing up effect of the iron on the rate of disappearance of the flux due to the losses in the iron. In this sense, an induction or spark coil resembles a spring like an archer's bow, for example. Without iron the coil is like a very stiff bow, so stiff that a given pull can deflect it but little and store but little energy. On the other hand, a spring so flexible as to be limp and have no life in returning to its normal position is like a coil filled with iron having no air-gap. An intermediate degree of stiffness, that gives a large deflection for a given pull and has the least permanent set, is nearest like the spark coil with a proper proportion of iron and air-gap, such as indicated by curve No. 3 in Fig. 1.



Returned energy is proportional in each case to area XQK, EPF, COD, and ANB, less area of hysteresis loop. Stored and returned energy is represented by a BH area, and the best ignition coil is the one showing the largest area (of the type COD) less the area of the loop, and having also a loop of moderate area

FIG. 1—*BH* CURVES OF EXCITATION
For the same maximum values of H, but with various amounts of iron.

Another analogy that applies quite directly to such an electrical and magnetic energy storing device as an ignition coil is the hydraulic ram. Fig. 2 shows such a ram modified to transfer the energy from the intermittent flow of a large volume of water at a low head to intermittent jets of a very small amount of water at a very high head or pressure. The hydraulic head is, of course, the equivalent of the battery voltage, and the

intermittent flow of water in the supply pipe stores energy of mass motion in the same way that the primary current stores up magnetic energy, i. e., flux-current energy. The automatic opening and closing of the main valve *K* duplicates the closing and opening of the contact points by the cam. For the condenser, we have the air chamber *A*. Both act much alike. The resistance of the pipe and throttle *S* are similar to the electrical resistance of the primary coil, and the so-called ballast resistance. The mass inertia of the water is like the inductance of the coil. The effect of iron in the spark coil can be duplicated by supposing some salt dis-

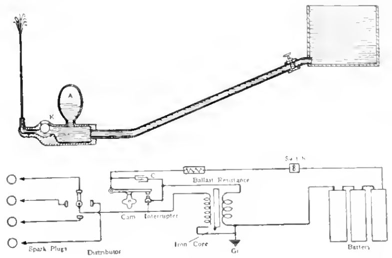


FIG. 2—COMPARISON OF HYDRAULIC RAM WITH AUTOMOBILE IGNITION CIRCUITS

solved in the water (hypothetical perhaps), that largely increases the specific gravity of the resulting solution. The flow is the same and the storage and release of energy is greater, quite as in the case of the addition of iron to the coil. If the solution becomes saturated and no more salt will be dissolved, the condition becomes similar to magnetic saturation. It is more difficult to imagine the equivalent of over-saturation and residual flux in the iron, but if a surplus of salt would, for example, cause the sudden stoppage of flow when the valve *K* closes, to start a whirling or rotary motion of the fluid so the energy of linear motion became partly absorbed in that of rotary form, the condition would somewhat resemble residual flux and iron losses.

With a given head of water and length of pipe it will take an appreciable interval of time for the water to accelerate to a full flow. The same is true of the electric current. This interval is called the time-constant of the spark coil, and the water pipe has a similar time-constant. If the valve operates too rapidly, the water does not have time to come to full velocity in the pipe, and so does not store its full energy. In the same way, if the engine being served by a spark coil of large time-constant is operated at such a high speed that full current is not reached, full energy is not stored and the spark is weakened.

Perhaps the valve K will only safely handle a certain flow of water without rapid deterioration. A throttle *S* may be used to control and limit the water flow. Likewise the ballast serves the same purpose in the electrical system, but has an additional function in that, if current is left on too long it heats up and increases its throttling action. As to the secondary of the spark coil, the intermittent jet from the ram at high velocity, but of small volume, is the equivalent of the ignition spark. A further mechanical elaboration of the ram could be worked out to give more exact equivalents of the secondary winding, but enough has been given to show the similarity of the two devices. It is seen then that the storing of low-potential energy from a battery in such form that it can be released at a high-potential and with great suddenness is a problem fundamentally simple, but to obtain maximum results requires a fine balancing of the elements of the system. When there is added to that the mechanical problems of rapidly but intermittently moving parts and the question of insulation of the suddenly released energy of the spark, it is not surprising that the art has known a variety of types of ignition apparatus.

Regulation of Automobile Lighting Generators

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Automobile Equipment Div.,
Westinghouse Electric & Mfg. Company

THERE are so many different makes and kinds of automobile lighting generators on the market that the average car owner does not have a very clear idea of the principles of operation of any of them. Essentially, they are all shunt generators with the addition of some means for reducing the field strength as the speed increases after the speed and output of the generator reach a certain value. The recent types also have electrically-operated contacts or cutouts for connecting them to the batteries when the voltage equals or slightly exceeds the battery voltage.

The machine may be a generator only, or a motor-generator, which can be used for both lighting and starting. Motor-generators are made with one armature winding, which can be used for both lighting and starting, or with separate windings on the same armature core. In the double armature winding type, a fine wire winding is used for generating, and another winding of fewer turns and low resistance gives the necessary starting torque as a motor. Generators or motor-generators operate at from one to three times engine speed. The ordinary methods of regulation can be used on either type of generator at either six or twelve volts.

The output required from the generator does not vary greatly on different makes of cars, but depends more on the individual drivers and the service in which

the cars are used. The current consumption of the six-volt electrical equipment on the average car is as follows:—

2—Sixteen candle-power headlights, taking about five amperes.
2—Two candle-power side or auxiliary lights, consuming about one ampere.
1—Two candle-power tail-light, one-half ampere.
1—Two candle-power dash-light, one-half ampere.
1—Starting motor, 250 amperes at start and 100 to 125 amperes cranking.
1—Ignition unit, three-fourths to two amperes.
1—Horn, three to six amperes average.
Extra equipments, such as searchlights, primers, etc.

From this list the current consumed under different operating conditions can be estimated. With the car

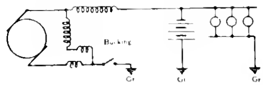

FIG. 1—CONNECTIONS OF DIFFERENTIAL GENERATOR WITH BUCKING SERIES COIL

running at night the current consumption is about seven amperes. With the car standing at night the current consumption is about two amperes. With the car running during the daytime the ignition current required varies from three-fourths to two amperes. In addition, the horn may be operated for a few seconds at frequent intervals and may average an appreciable ampere-hour consumption. The starting motor may be operated at any time for periods of from five seconds to five minutes.

The difficulty in making a satisfactory generator application is due to the variable consumption of current. The car may be operated for considerable periods at very slow speed at night. It may be left standing at night for many hours with very little running to recharge the battery. The starting motor may be operated frequently and for rather long periods due to ignition or carburetor trouble. For these reasons, one owner may operate his car so that the ampere-hours consumed by the starting motor, lamps and ignition per hour the car is driven may be three or four times the ampere-hours required by another owner. As the generator only charges when the engine is running, and as the current

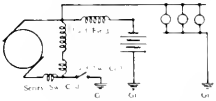

FIG. 2—MODIFIED DIFFERENTIAL CONNECTION
Whereby the battery continues to charge when the lights are on.

consumed has no real relation to the engine speed, it is apparent that the generator itself cannot take care of these conditions, but the battery must be depended upon to average up the output requirements.

Fortunately, the storage battery in itself is a good regulator and is really more flexible than most any other piece of electrical apparatus. It will stand a great deal of overcharging without damage, and in this way can take care of an average input greatly in excess of the average output. The important thing is to charge it at a sufficiently high rate and at sufficiently low car speed in miles per hour. This maximum rate should be about two amperes per positive plate of the ordinary starting and lighting battery. If the generator begins charging at 8 to 10 miles per hour and carries the total night load of seven to eight amperes at from 12.5 to 15 miles per hour the operation of the system should be satisfactory. The average charging current at speeds of 10 to 20 miles per hour should be about eight or ten amperes, depending somewhat on the method of generator regulation.

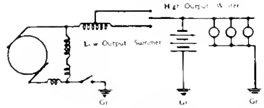

FIG. 3—MODIFICATION TO ALLOW THE OPERATOR TO ADJUST THE AMOUNT OF BUCKING ACTION

Three general systems of regulation are used in recent types of generators, the general systems being also modified by different manufacturers in minor ways. These three systems with their modifications are as follows:—

BUCKING SERIES

Machines of this type are essentially differential compound generators with internal connections such as shown in Fig. 1. The series field increases in strength with increase of output and opposes the shunt field, thereby reducing the resultant field and keeping the voltage and current within permissible limits. With this type of generator the storage battery really regulates the voltage and the series winding and speed of the generator determine the ampere output. Three important modifications of this system are used. A common arrangement consists in bringing out a terminal between the armature and series field and having the lamp load connected to this terminal, as in Fig. 2. In this way the generator operates as a shunt machine in so far as the lamp load is concerned, and for this reason will give an increased output when the lamps are turned on over the output given to the battery only. This compensates in a

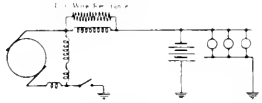

FIG. 4—SERIES FIELD SHUNTED BY IRON-WIRE BALLAST

measure for the difference in output required by a driver who uses his car mostly at night and one who does a great deal of touring in the daytime. A second scheme, shown in Fig. 3, allows the driver to adjust the output of the machine. A two-position switch is used, and with one connection the output at a given speed from the generator may be ten amperes, while with the other position the output may be 15 to 20 amperes. This scheme, if properly used by the car owner, will compensate for the difference in output required in summer and winter driving, or for cases where increase

in output is required due to slow driving at night. The third scheme consists of a differential compound generator with a shunt to the series winding. The shunt is in the form of a ballast, as in Fig. 4. This device increases the effect of the series winding at high currents and gives a more nearly constant current output. Its principal advantage is the increase in output obtained at low speeds where the machine can be made to operate practically as a shunt generator. The ballast may be made in

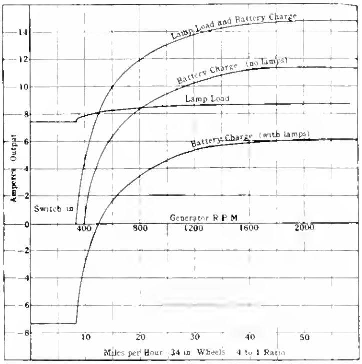

FIG. 5—PERFORMANCE CHARACTERISTICS OF A GENERATOR OF THE TYPE SHOWN IN FIG. 2.

any of the standard forms using a resistance which has a high temperature coefficient. Fig. 5 shows the output as a generator with the special lamp terminal connections shown in Fig. 2. Somewhat similar curves are obtained by the other modifications of the bucking series types of regulation.

THIRD BRUSH

Machines of this type usually have only a shunt winding, and the decrease in generator field strength is obtained by means of a third brush on the commutator. Two different wiring arrangements are used. The one shown in Fig. 6 has a shunt field connected from the third brush to one of the main brushes, so that when the load on the generator increases the voltage across the shunt winding will decrease due to the distortion of the

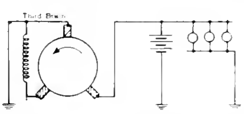

FIG. 6—THIRD BRUSH REGULATION OF A FOUR-POLE MACHINE

field caused by the armature ampere-turns, as shown in Fig. 7. Fig. 8 shows the output of the generator with this style of regulation and also the voltage across the shunt winding. The current in the shunt winding, which decreases as the armature current increases, tends to keep down the maximum temperature rise of the generator and increases the efficiency. The second scheme for using the third brush is shown in Fig. 9. With this arrangement, cross currents are set up in the armature conductors between the third brush and one of the main brushes in such a way that they tend to demagnetize the field of the generator. Local currents in the armature conductors under the main brushes also have this same effect, and a considerable reduction in the generator field strength at high speed can be obtained by using an especially wide brush for the main brushes. This second scheme of third brush regulation gives essentially the same regulation as the first scheme, but probably the generator is not quite as efficient.

MECHANICAL REGULATOR

The essential principle of the separate regulator consists of a pair of contacts operated by small electro-

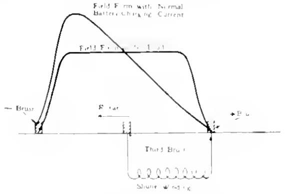

FIG. 7—MAGNETIC FIELD DISTRIBUTION OBTAINED WITH SCHEME SHOWN IN FIG. 6

This curve explains graphically why the shunt field decreases as the armature current increases.

magnets, which cut resistance in and out of the shunt field circuit, as shown in Fig. 10. These regulators are made in a number of different forms, but may be classed as voltage or current regulators. The voltage regulator, as its name implies, regulates the field strength of the generator to keep the voltage within very close limits, as shown in Fig. 11. Machines of this class may be used without a storage battery without danger of burning out the lamps, although the voltage is not quite so stable, especially at high speed. As shown in Fig. 12, the voltage is regulated through a range which permits the charging of a storage battery at a high rate when the battery voltage is low and at a much lower rate when the battery voltage is high. In other words, the charging current depends on the state of charge of the battery and its corresponding voltage under normal charging condi-

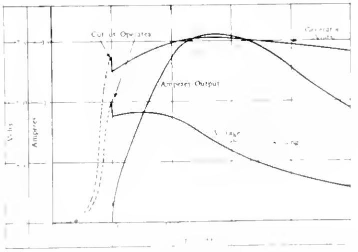

FIG. 8—PERFORMANCE OF THIRD BRUSH GENERATOR ... SHOWN IN FIG. 6

tions. This is a very desirable characteristic and in itself will take care of widely different conditions of current demand on the generator and battery.

The current regulator is similar to the voltage regulator, except that the magnet coils are wound to regulate the output for constant current instead of for constant voltage. The main coil of the regulator, which opens and closes the regulator contacts, is in series with the

battery instead of in shunt to it. This type of regulator does not seem to have any particular advantage over the third brush or bucking series type of inherent regulation, as the battery is still depended upon to determine the voltage, and the additional complication of the regulator is hardly justified by the fact that the current output of the generator is constant above a certain speed. Modifications of the current regulator are made which cut resistance in series with the shunt field in one or two steps. The output obtained from a generator with this type of regulation increases up to a certain point, at

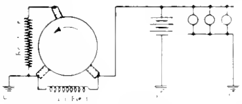

FIG. 9—ANOTHER METHOD OF REGULATING BY MEANS OF A THIRD BRUSH

which the resistance is cut in circuit with the shunt field and the output is reduced to a much lower value. As the generator speeds up the output again increases from this figure.

CONCLUSIONS

All of these types of regulation have been used successfully on automobiles. The essential thing is to have a generator which will give an output at low speed in car-miles per hour and which has a sufficiently high average output at speeds of 10 to 20 miles per hour, and at the same time does not exceed a maximum current which will cause the battery to gas an excessive amount or will damage it by overheating.

The variation in service conditions produced by the different habits of individual car operators causes the output of the generator and battery to differ through

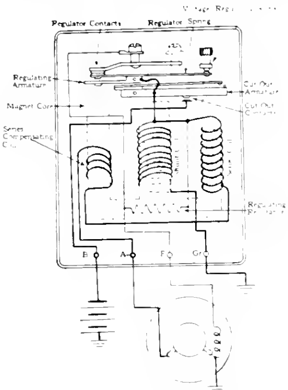

FIG. 10—CONNECTIONS OF COMBINATION VOLTAGE REGULATOR AND CUT-OUT

wider ranges than do the outputs obtained from generators with different systems of regulation. The generator must be made so that it will continue to give the regulation and output for which it was originally designed, and so that it cannot be damaged by overheating for any conditions of operation. It must also be sufficiently rugged to stand up under the service given it on an automobile with a minimum of attention. Any of the previously mentioned schemes of regulation should give satisfactory results if the generator has sufficient capacity and output at the proper speed in car-miles per hour, especially if the car owner will give the system a very reasonable amount of attention. It does not take an engineer to read a voltmeter or a hydrometer, and it is as important that the battery be refilled with pure water now and then as it is that the crank case be sup-

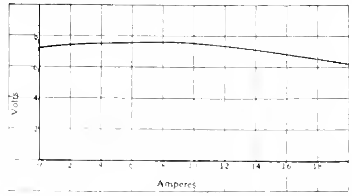

FIG. 11—REGULATION CHARACTERISTIC OF AUTOMOBILE GENERATOR AND REGULATOR

plied with oil and the gasoline tank with gasoline. If a driver finds that the battery is overcharging it is a very simple thing to leave the headlights on for a few hours some evening when the car is standing, or operate the engine with the starting motor for a few minutes; likewise, if the battery shows a tendency to run down, care should be taken not to operate the car at night with both sidelights and headlights burning, leave it standing at night with the headlights burning in place of the sidelights, or to operate the engine with the starting motor for two or three minutes at a time when starting up. If the engine fails to start immediately when the starting switch is closed, an investigation should be made to determine the cause for its not starting. Usually the discovery will be made that there is no gasoline, that the ignition switch is not turned on or that the engine does not start for some other reason, and simply turning it

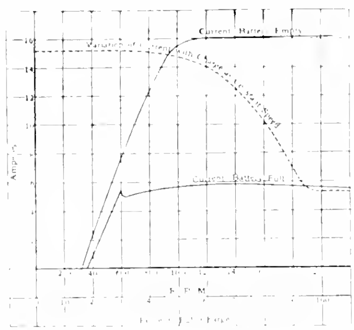

FIG. 12—BATTERY CHARGING CHARACTERISTICS OF GENERATOR AND REGULATOR UNDER VARYING CONDITIONS OF LOAD AND BATTERY CHARGING

over on the starting motor will not start it. There is nothing mysterious about the operation of the lighting equipment on an automobile, and the individual owner can do more to make the operation of the system on his car a success by paying attention to some of these points than the electrical manufacturers can by designing different schemes of regulation.

Mechanical Applications of Generators and Motors

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A PIECE of electrical apparatus for an automobile may be excellent in construction and performance, and yet if it is not properly mounted or driven it may fail to function properly. Correct application has not always been given the attention that it deserves, and the electrical apparatus has been blamed, unjustly, for troubles due to faulty mechanical application. The following description gives the salient features and methods adopted to secure good results. No attempt will be made to cover all applications but typical ones that appear to represent good practice.

The machines covered are the generators for lighting and for charging the storage batteries, the magnetos and other ignition devices and the motors for starting the engines. These are nearly always mounted on some part of the engine.

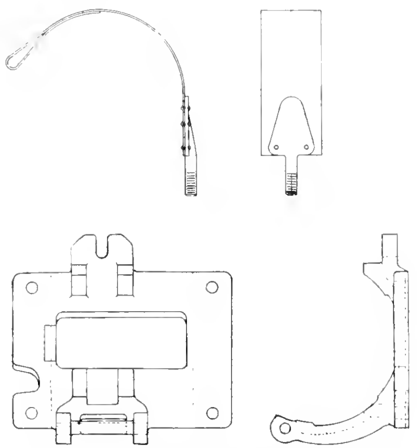

FIG. 1—MOUNTING BRACKET AND CLAMPING STRAP FOR A ROUND GENERATOR

METHODS OF SUPPORT

The machine is supported by a bracket, usually extending underneath, to which it is strapped or bolted. These brackets are sometimes made integral with the engine castings, or more often separate castings are made and bolted to suitable pads on the engine. The latter is a more flexible arrangement, as it allows for brackets for different types and shapes of machines without change to the engine, a desirable feature from the engine builder's standpoint. The material is usually cast iron, though aluminum may be used where lightness is especially important. Fig. 1 shows a mounting bracket and clamping strap for a round generator. Fig. 2 shows a bracket for a rectangular frame starting motor. Figs. 3 and 4 show applications of a generator with an ignition device mounted on it, and a motor to a standard engine, using brackets which are bolted to pads on the crank case. The housing on the end of the motor for the pinion shaft, Fig. 4, has a flange which is bolted to a machined surface on the flywheel housing. The nose of the housing is generally provided with a circular ring, which slides into a corresponding circular hole in the flywheel housing. Thus is secured an arrangement with a very rigid support and a simple and accurate alignment in assembling without fitting. Careful attention has been paid to details of oiling, etc.

Where greater rigidity is required, as for instance in the case of high-torque motors of the round type, the bracket is strengthened and the strap clamp is replaced by a semi-circular casting bolted to the bracket. Another modification that is very satisfactory, where the

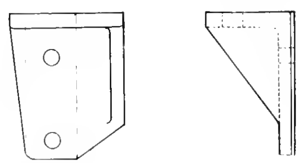

FIG. 2—BRACKET FOR RECTANGULAR FRAME STARTING MOTOR

flywheel housing is made to suit, is to support the motor entirely from the housing flange and do away with any bracket support underneath. Such a design is shown in Fig. 5. A similar arrangement is also used for generators. A different type of flange for motor mounting is given in Fig. 6. In this case an outboard bearing for the shaft is provided in the flywheel housing. Occasionally applications come up where it is not possible to attach mounting brackets to the engine crank case. An arrangement worked out for such a case mounts the motor on the engine arm, as per Fig. 7. When properly designed, the machining can be made to provide for properly placing the apparatus so that little or no fitting or adjustment is required.

Points to be taken into account in designing application fittings can be summarized as follows:—

Accessibility.
Strength to meet service requirements.
Ease of assembly.
Appearance.
Minimum weight.
Minimum machining.

METHODS OF CONNECTION TO ENGINE

Two general methods have to be employed, one for generators and ignition devices, which are driven con-

tinuously, and the other for motors which are required to run only during the starting period.

The more usual method of connecting up generators or magnetos to the driver shaft is by means of couplings. These vary widely in design, but are usually of the flexible type. It should be borne in mind, however, that a

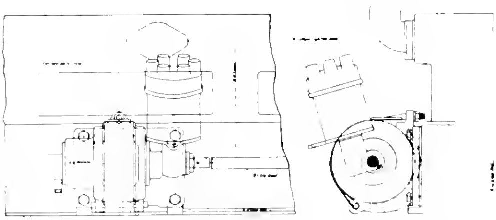

FIG. 3—METHOD OF MOUNTING A GENERATOR WITH AN IGNITION DEVICE CONNECTED TO IT

so-called flexible coupling should be well aligned for the best results. Sometimes the water pump of the engine, the generator and the magneto are all in tandem and driven from the same shaft. This requires a good coordination of mountings and couplings for the best results. A tandem arrangement is not always possible because of space limitations. In such cases the best arrangement is to use a generator with the ignition device mounted on it and driven from its shaft. Where a magneto is used, one of the two machines is placed above the other and the upper one driven from the pump shaft by gearing or a chain. This is not a particularly desirable combination and should be avoided wherever possible. When used, a housing for gears or chain is desirable, and with a chain drive a readily accessible and easily adjusted device should be provided for taking up the chain stretch.

A generator mounting, tending towards simplification, is similar to Fig. 5, and was briefly mentioned above.

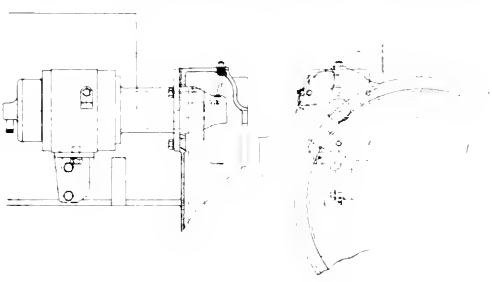

FIG. 4—METHOD OF MOUNTING A STARTING MOTOR ON A TYPICAL ENGINE

Using the brackets shown in Fig. 2.

The machine is bolted to the gear case by means of a flange on the end bracket, the driving gear or sprocket being mounted directly on the generator shaft. This arrangement does away with bearings, shafts and couplings required by the method of coupling. Ignition devices may be attached to the machine, if desired. Generators, as a rule, have been designed to run at moderate speeds because of the tendency to noise with high pitch line speeds and space limitations.

Belt drive for generators, while employed to some extent, has not met with a wide use because of the difficulty in preventing belt slippage over a wide range of

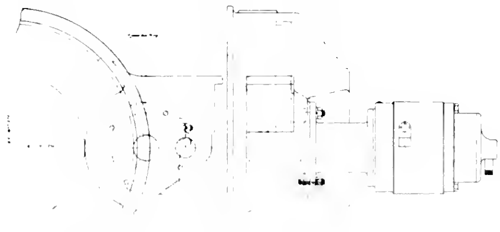

FIG. 5—METHOD OF MOUNTING A STARTING MOTOR ON THE FLY-WHEEL HOUSING FLANGE

speed. When employed a belt-tightening device must be used.

Starting motors are nearly always geared to the crank shaft, the most common way being to cut teeth in the rim of the flywheel and make use of it as a gear-wheel. The motor may be directly connected to the flywheel through a pinion on the armature shaft, giving a single reduction drive, or an intermediate gear may be used, thus giving a double reduction drive. There is a noticeable tendency to go to the single reduction arrangement, as the increase in the size of the motor, due to its lower speed, is largely offset by the elimination of the extra gear, counter shaft, clutch, etc. The double reduction arrangement requires the use of an overrunning clutch, to allow the engine to run ahead of the motor when firing takes place; otherwise the armature would reach a destructive speed before the engaging pinion could be released. On all but the largest sizes of engines, teeth cut in the cast iron flywheel rims appear to be fairly satisfactory. In the largest sizes a steel gear ring is mounted on the flywheel. The starting motors are

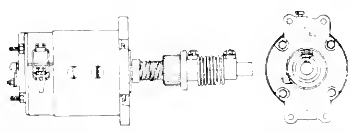

FIG. 6—ANOTHER TYPE OF FLANGE MOUNTING

thrown into engagement by shifting a pinion into mesh with the flywheel teeth.

Gear shifting mechanisms may be generally classified into non-automatic and automatic.

Non-automatic, mostly used with double reduction applications. The pinion is thrown into mesh through a fork on a push rod operated by a lever in the car. Simultaneously with the shifting of the pinion, the electrical circuit to the motor is controlled so that an initial slow speed is obtained for engaging the teeth of the pinion with those of the flywheel and a final closing of the circuit is made after the pinion is in full mesh. The gear

teeth are chamfered to secure ready meshing. Demeshing is accomplished by releasing the lever, the return being caused by a spring. This arrangement, as explained above, requires an overrunning clutch. In a modification of this scheme, which is somewhat simpler, a single reduction motor is employed, the pinion being placed on a square extension of the armature shaft. Electrical connections to the motor are not made until the pinion has been shifted into full mesh.

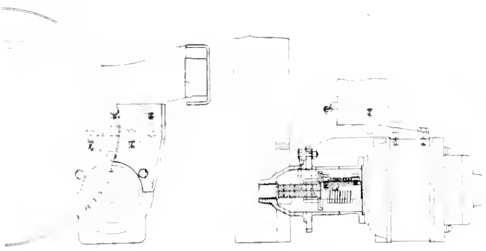

FIG. 7—METHOD OF MOUNTING STARTING MOTOR ON THE ENGINE ARM

Automatic—With this scheme the driver has merely to close the starting switch, the pinion then being automatically engaged with the flywheel before the motor begins to crank the engine. There are two automatic types, the electrical and the mechanical. In the electrical, as soon as the motor circuit is closed, the pinion is drawn into mesh by a magnetic action in the motor itself and against a spring, tending to hold the pinion in the off position. As soon as the engine fires, the current through the motor, due to the load being taken off, is decreased, thus reducing the magnetic pull to such a small value that the spring returns the pinion to the off position. The gear teeth are chamfered and a spiral tooth is used to facilitate meshing and demeshing as shown in Fig. 9. In the mechanical type of shift a special threaded shaft is fitted to the motor. The pinion is also threaded and placed on the threaded part of the shaft. As soon as the shaft of the motor begins to revolve the pinion moves over into mesh, being kept from turning by its inertia. As soon as the engine fires, the action is reversed and the pinion moves out of mesh. The pinion is provided with an unbalanced weight to facilitate its action when the motor is first started and also to prevent it from working into mesh from vibration when the car is running. For meshing more readily the flywheel gear teeth are chamfered if of steel, but are left unchamfered if of cast iron.

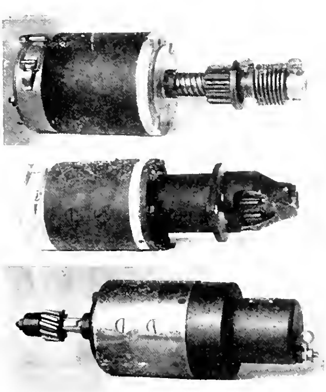

FIG. 8—TYPICAL METHODS OF PINION MESHING
Top—Spiral screw shift.
Middle—Spiral screw shift for enclosed flywheel.
Bottom—Magnetic shift.

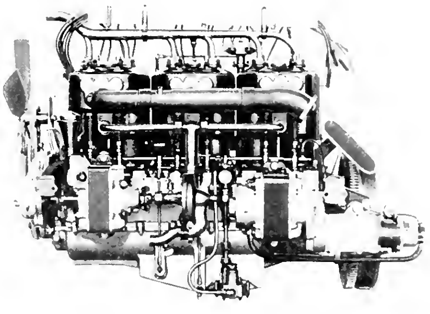

FIG. 9—APPLICATION OF STARTING MOTOR, GENERATOR AND IGNITION SET TO A PIERCE-ARROW SIX-CYLINDER ENGINE
The magnetic type of gear shift is shown at the right of the starting motor, meshing with teeth on the flywheel.

In another type of drive a single machine is used, performing both the function of starting and lighting, and commonly called a motor-generator. A more correct term is motor and generator. Below certain speeds this machine operates as a motor, and above them as a generator. The machine is in continuous operation and a chain drive is used. Sometimes the chain is placed at the front end of the engine and enclosed in a gear case; sometimes it is at the rear of the engine and the chain is run open. The points to be observed in this drive are, that the chains should be of ample size, the diameter of the sprockets should not be too small, centers should be as short as possible, the alignment good, and means should be provided for taking up the chain stretch.

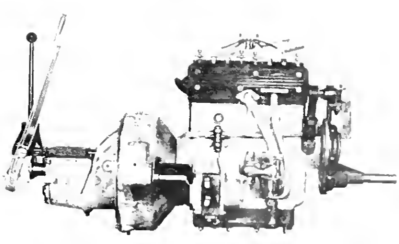

FIG. 10—APPLICATION OF STA[illegible] MOTOR TO [illegible] ENGINE

Careful consideration of all the conditions involved and due attention to details are necessary for any successful application of electrical apparatus to an automobile.

Control Switches for Electrical Equipment

OF GAS-DRIVEN AUTOMOBILES

B. D. Kunkle

THE electrical control equipment for automobiles varies with the type and number of electrical units comprising the application. Before the advent of electric starting and lighting, the control consisted of a simple on and off switch to control the ignition circuit. This is still the case on cars using the gas lighting systems. The addition of the electric starting and lighting has made necessary the use of switches to control these functions.

LIGHTING CIRCUITS

The control of the lighting equipment is divided into two features; one governs the circuit of the generator to the battery and the other controls the lighting circuit. The circuit from the generator to the battery is usually controlled by an automatic magnetic cut-out with current and potential coils, the complete mechanism in most cases being built onto the generator to avoid outside wiring. This relay closes from generator to battery, when the generator voltage reaches a predetermined value for which the cut-out is set, which is the point where the generator starts to charge the battery. This pull-in coil operates against a return spring and the cut-out switch is automatically opened by the action of this spring and the reverse current coil. When the decreasing speed of the generator allows the voltage to drop below that of the battery and begins to draw a discharge or reverse current through the current coil of the relay, the relay releases. This makes the closing and opening of the relay automatic with varying speeds of the engine.

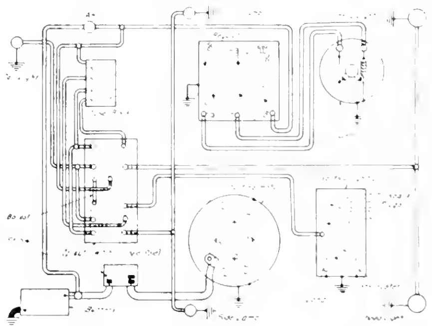

FIG. 1—CONNECTIONS FOR GENERATOR
With separate regulator, vertical ignition unit, starting motor, ammeter, fuse block, starting switch and single-pole ignition and lighting switch.

The switches controlling the circuits to the lamps are of the single-pole type, one side of the lamps being connected directly to the battery, either by a wire or by being grounded to the frame of the car as in the case of the single-wire system. The switches themselves usually consists of a series of push or pull button units, one for each combination of lights and all mounted on the same plate, or they may consist of some rotating finger or contact scheme, which with successive positions of the operating handle will complete the circuits for the combinations desired. As the voltage employed in automobile equipments seldom exceeds 12 volts and the current for any lighting circuit is rarely over five amperes and as the insulation distances necessary are quite small, the switches may be made very compact and the construction of parts as limited as is consistent with durability.

Locking features are incorporated in many of the designs to prevent tampering with the lights. In most cases this is taken care of by using a removable handle, which the car operator can take with him when he leaves the car. In some designs a standard form of lock is mounted in the face plate of the switch and locks the mechanism in any desired position.

The majority of applications now require one of two lighting combinations, each group of which may be obtained with one operation of button or lever. One of these combinations is off—head and tail—side and tail. The other combination is off—head and tail—head dim and tail. The dimming is accomplished either by connecting the two head lamps in series or by connecting a resistance in the lamp circuit. The latter scheme, while less economical from the standpoint of operation, is the one usually employed, as it avoids the necessity of running two separate wires from the switch to each head lamp. As the dimming of head lamps is becoming more common, separate dimming switches are often provided, located conveniently for the car operator. The normal position of the switch shunts the dimmer, but when opened throws the dimmer in series with the head lights. In lighting applications where they are included, separate push or pull button switches are usually provided for operating instrument-dome or pillar lights. The law in some states requires the closing of the tail lamp circuit at the lamp in order that the car operator may be certain that the tail lamp is lighted. The closing and opening of the circuit is usually done by engaging or disengaging a bayonet type of connector attached to the lamp cable and fitting a suitable receptacle in the base of the lamp.

In most cases where electric lighting is used, but not electric starting, leads are brought out from the generator and a switch is provided for opening the shunt field circuit of the generator to prevent overcharging of the

battery. This scheme is extensively used in Europe, where electric starting is not as generally employed as in America.

STARTING MOTOR CONTROL

As in the case of the lights, the starting motor is usually controlled by a single-pole switch in the motor circuit. Since the voltage is low the current of the starting motor is relatively high, accordingly the starting switch is made suitable for carrying from three to four hundred amperes for as long as the battery will stand up under the load condition. The normal cranking current taken by the motor after the engine has started to turn over varies from 110 to 175 amperes, depending upon the size of the engine. In order to assure satisfactory operation, the starting switch must be capable of breaking this current repeatedly without undue burning of contacts. In the construction of the earlier starting switches, the circuit was usually made and broken by bridging two terminal contacts with a solid metal disc. This form has been replaced almost entirely by contacts having a slight wipe or rock between contact surfaces. This action between contacts prevents burning of surfaces from interfering with the operation of the switch. The starting switch is usually operated by a foot pedal or push button, and remains closed only while held in that position by the car operator. A magnetic relay is sometimes used in the motor circuit instead of a foot-operated switch, the relay being controlled by a push button. The latter arrangement simplifies the starting operation and, as the relay is mounted close to the motor, it avoids the necessity of carrying the heavy starting motor cables to the toe board or dash. Typical diagrams for both lighting and starting combinations with ignition are shown in Figs. 1 and 2.

Where the motor and generator are combined in one unit the switching arrangement is usually one of two combinations, although the exact construction may vary. One of these combinations is a starting switch and magnetic relay mounted in the same case and attached to the car body, or made and mounted in a manner similar to that employed where separate units are used. The other arrangement connects the unit directly to the battery, allowing it to remain constantly in circuit so long as the switch is closed. With this combination the machine will operate as a motor below the speed at which its voltage will balance the battery voltage or as a generator above this point. This scheme is sometimes termed the "non-stall" combination, as the automatic change from generator to motor keeps the engine turning over in case of instantaneous failure of spark or gas.

ARRANGEMENT OF CONTROL UNITS

The location of the control units varies greatly with the different type of automobiles, the more common location being the instrument board or cowl dash. The lighting and ignition circuit control must necessarily be within easy reach of the driver. In some instances the control switches are located directly under the steering wheel. In these cases the switches are mounted on a suitable casing attached to the steering column. A scheme that is meeting with some favor is to provide a die casting, of neat design, made to carry all switches and instruments, including instrument lamp and fuse blocks. This plate is mounted on the dash or on a special instrument board. This scheme presents advantages in that all the small wiring usually found on the back of the dash can be done before the plate is mounted in place and leaves only the main circuits to be connected up to the switch terminals when the car is assembled.

On one car a lighting and horn switch combination is used, consisting of a large knob or turn button on a small steel rod passing up through the center of the steering column, the knob being located above and in the center of the starting wheel. At the lower end of the steering column the rod connects to a special lighting and horn switch. Depressing the knob closes the horn motor circuit, while rotation of the knob operates the lighting switch.

Another scheme, which probably makes the most desirable combination of all, is to have the instruments

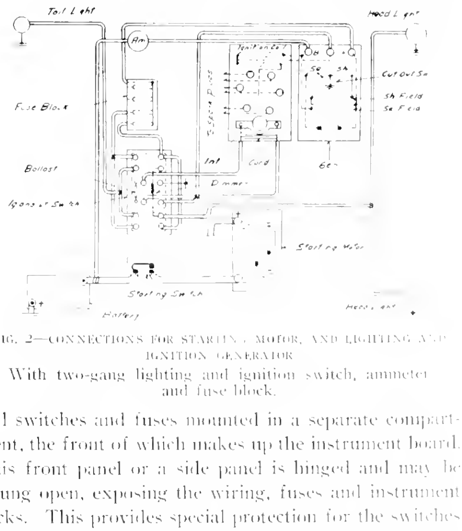

FIG. 2—CONNECTIONS FOR STARTING MOTOR, AND LIGHTING AND IGNITION GENERATOR

With two-gang lighting and ignition switch, ammeter and fuse block.

and switches and fuses mounted in a separate compartment, the front of which makes up the instrument board. This front panel or a side panel is hinged and may be swung open, exposing the wiring, fuses and instrument backs. This provides special protection for the switches and instruments and locates the small interconnecting wiring where it can be conveniently inspected. This arrangement is somewhat expensive as regards first cost, but goes a long way toward the prevention of trouble

While as yet there is no equipment for the control of the electrical apparatus on automobiles that may be called standard, the scheme last mentioned is the one growing most in favor. Having the parts grouped together and at the same time accessible assures a greater amount of attention being given the wires and connections. Facilitating the inspection of parts is the best insurance against trouble with the electrical equipment and greatly simplifies the locating of trouble whenever it occurs.

The Application of Electric Starting and Lighting to the Ford Car

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Automobile Equipment Dept.,
Westinghouse Electric & Mfg. Company

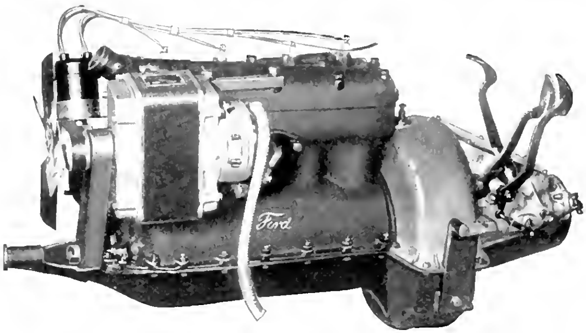


FIG. 1—COMPLETE STARTING, LIGHTING AND IGNITION INSTALLATION ON A FORD ENGINE

THE problem of applying starting and lighting sets to the Ford car resolves itself finally into the selection of a durable and satisfactory method of driving a single motor and generator unit from the Ford engine crank shaft. Because of the fact that there are no exposed moving parts on the power plant, excepting the crank shaft at the forward end of the motor where the fan pulley is mounted, it becomes necessary to use a single unit for both starting motor and lighting generator. The space available is of such a nature that a silent chain offers the only suitable means for driving, and is so limited that the largest chain that can be used is one inch wide and three eighths inch pitch. The width is determined by the shape of the engine base, while the pitch is determined by the armature-shaft crank-shaft ratio. The smallest pinion that a silent chain will run over satisfactorily is 15 teeth, except some specially

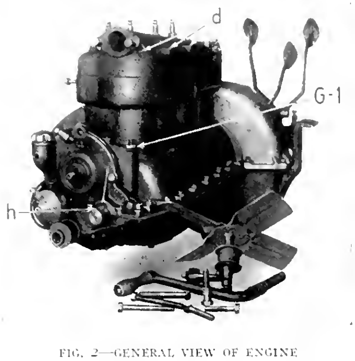


FIG. 2—GENERAL VIEW OF ENGINE
Showing space available on engine for mounting starting unit

designed chains which will operate over 13 tooth sprockets. The Ford engine requires approximately 75 pounds torque at one foot radius on the crank shart to start it under all conditions. There is just space enough to mount a starting motor that will give this torque, plus a safety factor, when geared approximately 2.25 : 1. With a 13 tooth pinion on the motor-generator shaft 29 teeth are needed on the crank-shaft sprocket to give this ratio. There is just space enough between the engine base and crank shaft to accommodate a 29-tooth three-eighths-inch pitch sprocket, as shown in Figs. 3 and 4.

It is well known by users of silent chains that any drive, where the center distances exceed seven inches between driving and driven sprocket, will develop at certain speeds a marked tendency to whip and vibrate. This tendency is further augmented on automobile engines by any critical speed that the engine may possess. If the critical speeds of the chain drive and engine happen to coincide, then one or the other must be altered to eliminate the critical speed or change the point at which it occurs.

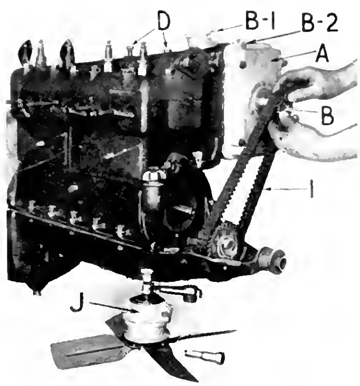


FIG. 3—FORD ENGINE WITH CRANK SHAFT AND CHAIN IN PLACE
Showing the limited space available.

The critical speed of the Ford engine occurs at approximately 1200 to 1400 r.p.m., or 30 to 35 miles per hour. At this speed there is no tendency for the gen-

erator driving chain to whip, and apparently it should be satisfactory, but there is another factor which has been a source of trouble and which is not at once apparent. The whole transmission line from engine to rear wheels has a critical speed at 13 to 19 miles per hour. The speed-time curve, Fig. 5, shows what occurs to the engine speed when running at 15 miles per hour with the engine under load, similar to propelling a car uphill. This condition is explained by the fact that a long propeller shaft of small diameter is used, and when each cylinder fires the propeller shaft and all other parts in the transmission train are put under torsion (approximately 350 pounds at one-foot radius). The flexibility of the parts under torsion permit the engine to gain speed over the car speed during the first part of each power stroke, and to lose speed during the last part of each power stroke. This fluctuation in the speed of the crank shaft produces severe whipping of the generator driving chain. If shorter center distances or a heavier chain were possible this condition might be met and solved without resort to other means, but with the limitations that exist it becomes necessary to absorb the crank shaft oscillations before they are transmitted to the motor-generator. This has been accomplished by incorporating a friction clutch in the driving sprocket, Figs. 6 and 7, so that the driving force on the chain can never exceed a fixed value. In order to provide for positive drive in starting, a spring pawl (*H-2*, Fig. 6) is used in conjunction with the friction clutch. Lubrication of the mechanism in this sprocket is provided by two small holes which carry leakage oil from the forward crank-shaft bearing to the inside of the sprocket.

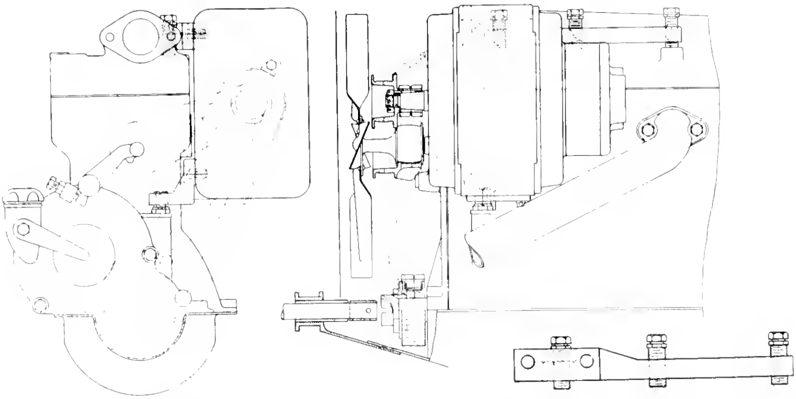


FIG. 4—DIAGRAM SHOWING APPLICATION OF STARTING AND LIGHTING OUTFIT TO FORD ENGINE
Showing the physical limitation of the design. The details of the method of adjusting the chain (at the top of the engine) are shown in the lower corner. No part of the engine has been altered

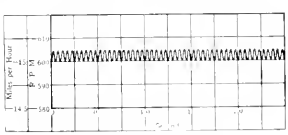
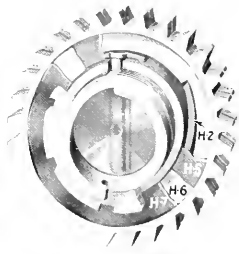


FIG. 5—VARIATION IN ENGINE SHAFT SPEED DUE TO SPRING IN TRANSMISSION

With all these precautions to protect the chain, it is still necessary to use a chain made from alloy steel, as it is found that, to be satisfactory, a chain must sustain a load of at least 6000 pounds on one strand without breaking. The determination of whether or not a chain is satisfactory is made by allowing the chain to run without adjustments until it rides over the sprocket teeth. A satisfactory chain will show no sign of distress under this condition. The nature of this application makes it impracticable to enclose the chain in an oil-proof case, and although a protecting case may be provided, and should be, there is still enough dust and grit that works into the chain to make an easy means of adjustment desirable. This adjustment has been worked out in one case, as shown in Fig. 4.



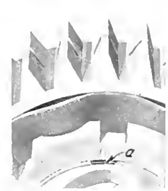


FIG. 6 FIG. 7

Fig. 6—Friction type driving sprocket, partly cut away to expose mechanism.

Fig. 7—Enlarged view of tension spring and sprocket clutch, showing method of adjustment.

There are many factors that bear upon the voltage of the system. The limitations of a six-volt motor-generator must be balanced against the extra cost of a twelve-volt battery. It should also be borne in mind that cable and contact resistance are only one-half the factor on

twelve-volt systems that they are on six volts. This applies particularly to single unit applications where the torque available from the motor-generator is the limiting factor.

Experience has shown that there is greater need for metal conduit or armored cable when wiring a used car

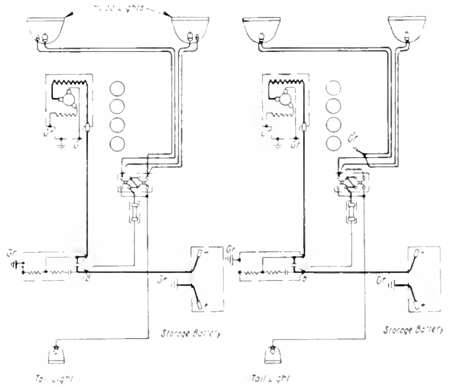
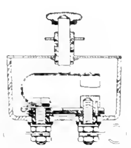
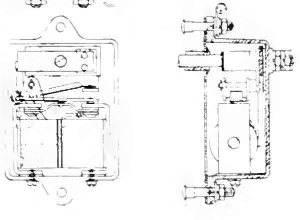


FIG. 8—WIRING DIAGRAMS OF FORD STARTING AND LIGHTING SYSTEM
The one at left is for double bulb head lamps, and the one at the right for single bulb lamps with dimmer.

than when making a factory installation on a new car, and therefore metal armored cable should be used for all the wiring on the Ford car, as these cars are probably more generally abused than any other. The saving in the number of wires and the simplification of installing leaves little excuse for other than the single conductor system of wiring. Fig. 8 shows very clearly how car wiring can be simplified when the single conductor system is used.

In order not to encumber the motor-generator with extra parts, and also to simplify the wiring of the car, it has been found advantageous to combine the starting





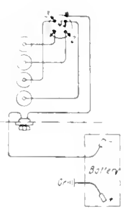


FIG. 9 FIG. 10

Fig. 9—Construction of starting switch and cut-out.
Fig. 10—Simple wiring scheme of self-contained ignition unit.

switch and generator cut-out into one unit, as shown in Fig. 9. This unit can be located in any convenient position, so that the starting button can be operated by one foot.

The motor-generator is designed to deliver maximum charging current at 20 miles per hour. By inherent regulation in the generator itself the charging current is reduced as the speed increases above 20 miles per hour. The generator is also designed so that it balances the battery at nine miles per hour and charges the battery at ten miles per hour. To prevent fluttering, the automatic cutout switch is set to close at ten to eleven miles per hour and to open at nine miles per hour. Service tests have shown that with this setting the battery will

FIG. 11—METHOD OF MOUNTING BATTERY AND BATTERY BOX ON THE RUNNING BOARD

be kept charged, even in delivery service, where the car averages 1.25 starts per mile of running.

The battery must be mounted in such a way as not to be loosened by road shocks, which would impair its life.

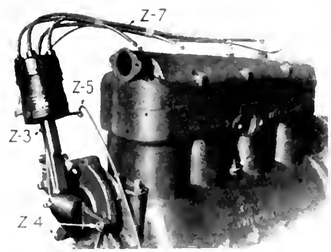


FIG. 12—COMPLETE IGNITION SET IN PLACE

This has been worked out as shown in Fig. 11. Easy removal of the battery is also essential.

To meet a demand for high-grade ignition for Ford cars a unit type of coil ignition has been applied, as shown in Fig. 12, which is entirely self-contained and

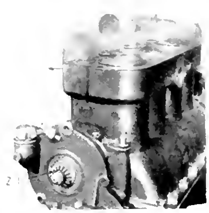


FIG. 13—THE SMALL BEVEL GEAR ON THE END OF THE CAM SHAFT REPLACES THE FORD TIMER ROLLER AND DRIVES THE IGNITION SHAFT

operates from the lighting battery. Only five wires are used, Fig. 10, the primary circuit and the four high-tension leads. The ignition unit can be removed from its supporting bracket without disturbing any other part, and is so arranged that there is no possibility of replacing it incorrectly. The application is simple, as

shown in Fig. 13. This type of ignition needs very little attention and offers distinct advantages over the vibrator coil system. There is practically no lag in the system, and therefore it is hardly necessary to shift the spark position for different running speeds. The relative firing time of each cylinder is definitely fixed and it follows that the engine will run smoothly. The spark is positive at all speeds; Ford cars equipped with this type of ignition without any other change have reached speeds as high as 60 miles per hour.

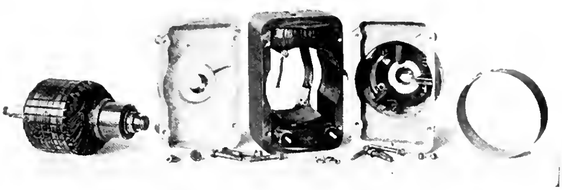


FIG. 14—DETAIL VIEW OF MOTOR GENERATOR

In general, there is probably more need for "foolproof" design in connection with the Ford car than with other cars, and therefore every effort has been put forth in this direction. The engineer cannot provide against the inclination of some men to fill the commutator space with grease or to put grease in the battery vents, but such points as chain adjustment and lubrication at frequent intervals should be arranged so that no serious damage will result if the apparatus is not given expert or frequent attention.

Electric Motors in Garages and Automobile Service Stations

Bernard Lester
Industrial Department,
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NOT many years ago automobiling was largely a pastime or sport and, like the game of golf, had its hazards, the overcoming of which was experienced with a certain relish. The automobilist, after his drive or tour, would relate heroically his mishaps and the methods employed in overcoming these, much as the golf player relates the embarassments and accomplishments of an afternoon upon the golf links.

Today, however, broadly speaking, the position of the automobile has changed and users of cars speak of the service they receive over long periods of time from their pleasure car or truck. Automobiles are used more and more on schedule. This has been accomplished not only by simplification and standardization in the construction of the machine itself, but by the establishment of service stations in almost every quarter for the maintenance and repair of automobiles and accessory equipment. This has become an industry in itself in which have been invested large amounts of capital and much skill. One looks for quick service—reliable service—low-priced service.

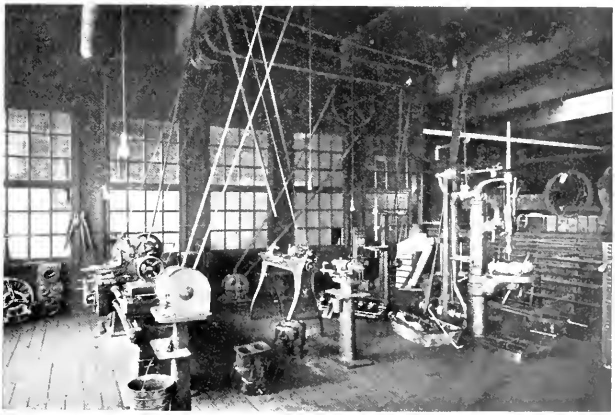


FIG. 1—INDUCTION MOTOR DRIVING A GROUP OF MACHINE TOOLS

Anyone who receives automobile repair bills is usually struck with the small cost of the materials used in making the repair compared to the large value of time expended as a measure of labor. While supplies and repair parts have been reduced in cost to the user, due to greater standardization and larger consumption, labor costs are being reduced, and can be further reduced by improved equipment in the garage. As is clearly shown in almost all manufacturing processes involving a repetition of operations, an increased investment in working tools brings a saving in labor more than compensating for the outlay. Where any appreciable volume of automobile repair work is done, it pays to install special machinery to do it, so that the flat labor is reduced to a minimum, due to a reduction in the time required to make repairs. And aside from the case of the garage doing general repair

work, the purchaser of the car cannot disconnect altogether in his mind the merits of the particular make of car and the merits of the agency service station which stands ready to back up the product. The two are closely associated with one another, for in the public mind the most successful car is the one which spends the least time in the repair shop.

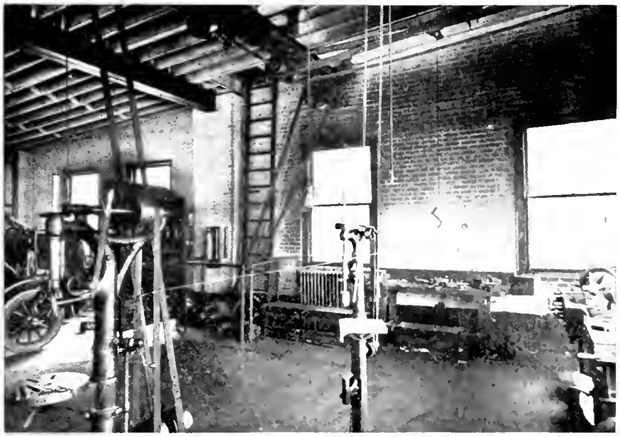


FIG. 2—DIRECT-CURRENT MOTOR DRIVING GROUP OF MACHINE TOOLS

FIG. 3—USING PORTABLE ELECTRIC TOOLS IN THE REPAIR SHOP

FIG. 4—PORTABLE MOTOR-DRIVEN TIRE PUMP IN USE IN A GARAGE

The use of electricity has to a remarkable degree made rapid and efficient automobile repair work possible. The electric light itself has facilitated repair work of all kinds and has reduced fire risk. Electric power is required in comparatively small units in all classes of automobile repair work, and the fact that it may be utilized at the very point at which it is required at a moment's notice—that it is safe, cleanly, quiet, reliable and usually cheap—has been an essential item in its favor. Space is also an item of importance in garages located in congested districts, and the power producers most desired are those which take up little room and may be mounted anywhere, for they are savers of rent or ground investment. And too, power units supplied for definite service which start and stop automatically breed economy by decreasing supervision and power consumed. Like every industry where systematic service is a keynote, these economies are not fully realized unless working schedules are carefully arranged for employes. The thoughtless and short-sighted employe is prone to conclude that the installation of labor-saving devices is intended only to cut down the work required of him, rather than to increase his working efficiency, improve his working conditions and open the opportunity for a higher class of service on his part which will ultimately increase his earnings. Therefore, with the installation of electric drive in its specialized form in the garage, and with the co-operation of employes and a thorough understanding of the function of electrically-driven machines, a great deal can be accomplished in actually quickening the schedule of repair work and thus increasing the profits. It is quite worth while to consider important definite uses for electric power and the advantages that are obtained,—not selecting an ideal garage, but simply those classes of motor application which are in everyday use to a greater or less extent.

Drill presses, planers, shapers, lathes, etc., in the metal-working shops are now usually motor driven, either by arranging them in groups and driving them from one motor, or by using motors on individual machines. The fact that such a drive is efficient, clean, safe and saving of useful floor space has been

fully demonstrated in the past. Belting and line shafting are largely eliminated. In these applications, therefore, electric drive has the same advantages in the garage and automobile repair shop that it has in the metal-working plant or machine shop.

FIG. 5—CLEANING CAR WITH A MOTOR-DRIVEN VACUUM CLEANER

Aside from such stationary equipment, however, which is used for machining small separate parts, there are frequently repairs to be made upon the car itself requiring machining operations which would be tedious were the car to be disassembled. The portable drill,

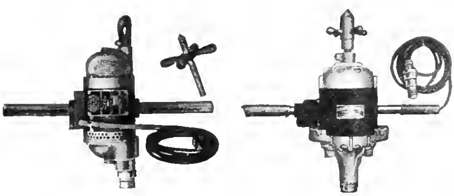


FIG. 6—TYPICAL ELECTRIC DRILLS

grinder and buffer are useful in this class of work. Little bench grinders or buffers are occasionally supplied with flexible shafts and used for semi-portable service.

Compressed air is a necessity of the garage and service station, principally for inflating tires, but also for cleaning upholstery and producing pressure for lifting oil, gasoline, etc. In the smaller garages, motor-driven tire pumps of the portable type are mounted upon little trucks. The unit is taken to the work and is usually non-automatic in starting and stopping. In the case of larger units, a stationary plant and an air tank are used, and an automatic pressure regulator starts and stops the motor-driven pump at pre-determined limits of air pressure. This system requires a piping system and longer hose connections.

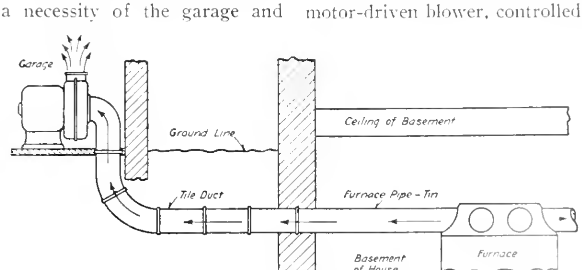


FIG. 9—METHOD OF HEATING SMALL GARAGE AT REAR OF RESIDENCE FROM A HOT-AIR FURNACE

Problems of heating and ventilating are very similar to those of any manufacturing establishment, although disc ventilating fans have been employed quite extensively to clear away dead gases, which are injurious to

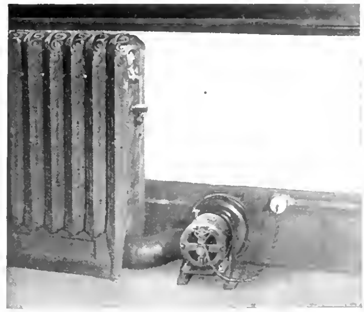


FIG. 7—HEATING AND VENTILATING THE GARAGE OFFICE
By means of a blower which brings in air from the outside and forces it through the radiator.

workmen. The office of the garage must necessarily be well heated and ventilated, and small motor-driven blowers are used extensively for this purpose.

One problem which has often come up to the owner of a private garage is the matter of heating it with-

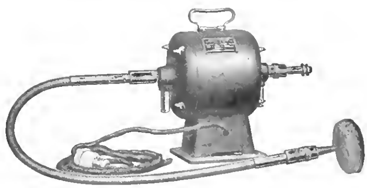


FIG. 8—BUFFING AND GRINDING MOTOR WITH FRICTION SHAFTING FOR POLISHING AND GRINDING WORK ON AUTOMOBILES

out danger of fire risk. Where the garage is close to the house a duct may be run through the ground and the hot air from the furnace forced to the garage by a small motor-driven blower, controlled by a snap switch in the house, thus heating the garage whenever desired.

Numerous other electrical devices are used in the electrical garage or repair shop, such as specialized motors, which are used to a considerable extent to operate the sewing machines employed in the manufacture and repair of automobile tops and seat covers. Electric vulcanizers are used for repairing tires, electric welders for repairing mudguards, and other electrical applications are continually being introduced.

Methods of Ignition

J. B. Dyer

IGNITION, with reference to the internal combustion engine, is the igniting of the explosive charge within the engine cylinder at the proper time to deliver the force of the expanding gases to the piston, and is one of the essentials which has passed through wide changes and improvements in the course of development. Good ignition can be obtained by igniting the charge at the

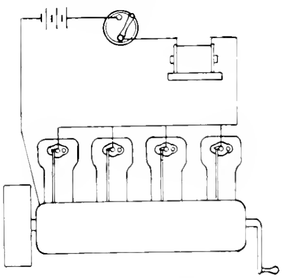


FIG. 1—MAKE AND BREAK TYPE OF ELECTRICAL IGNITION

proper time with uniformity on varying speeds. It would seem at first thought to be a simple matter to construct a reliable machine to accomplish this, but the following description of the different improvements will show how much time and thought have been necessary to develop the present ignition system.

The earlier forms of ignition apparatus were designed by the engine builder and, naturally, mechanical methods were used. The first successful ignition was the hot tube type. In starting the engine it is necessary first to heat the tube to a red heat, then inject a charge of gas into the cylinder and compress it. This charge of gas under compression becomes explosive and will ignite from the hot tube. The engine then turns and the charge is fired each time as it is compressed to the explosive state. The heat of the burning gas is sufficient to keep the tube hot. To secure the best results the time of igniting must occur at different positions varying with the speed and the quality of the charge.

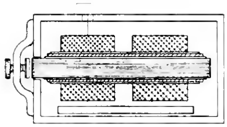


FIG. 2

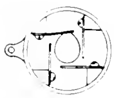


FIG. 3

Fig. 2—Vibrator coil for jump spark ignition.
Fig. 3—Rotating cam for timer for jump spark ignition.

There is a difference in time between the igniting and the total combustion of the charge. This lag with equal quality of mixture remains constant with varying speed, which necessitates having a means whereby ignition will occur earlier for the higher speeds and later for the lower speeds in order that the force of the expanding gas will be applied to the pistons in their most efficient position. For this reason the hot tube ignition is confined to the constant-speed stationary engine.

Make and break was the first type of electrical ignition. The equipment consisted of a coil of about 200 turns of No. 16 to No. 20 insulated copper wire wound around a soft iron wire core, a contact device inside the cylinder operated by a cam mechanism driven by the engine to close and open the contacts at a set time, a switch and a source of direct-current, either battery or electric generator. When the contact, Fig. 1, is closed a current of from two to five amperes flows through the coil; when the contact is opened, the sudden break in the circuit causes an inductive kick, forming an arc 1/8 to 5/16 inch long between the opening contacts, thus igniting the charge. To obtain different positions of igniting required a complicated mechanism. There was much trouble experienced by gas leaking around the movable rod protruding through the cylinder walls. It was also difficult to keep the contacts clean from carbon

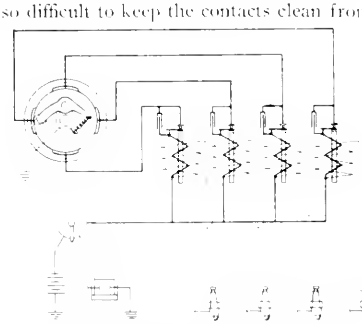


FIG. 4—DIAGRAM OF JUMP SPARK SYSTEM

and from burning. The moving parts were necessarily heavy and noisy and a large number of parts were required for multiple cylinders.

Jump spark ignition, as it was termed at that time, was next in the line of improvements. With this system the contacts were brought outside the cylinder, eliminating the leaky movable rod, and burned and dirty contacts, and in place a spark plug was used. It was thus easier to get the timing range necessary for the different positions of igniting. The equipment necessary was one coil for each cylinder with a primary winding of about 200 turns of No. 20 wire, over which was the secondary winding, usually of two sections, with a total of about 15 000 turns of fine wire (No. 35), a vibrator being connected in series with the primary circuit of this coil, Fig. 2; a low-tension distributor with as many points as cylinders, the cam rotating at one-half engine speed for four-cycle engines, Fig. 3; a spark plug for each cylinder, a switch and a source of energy. Fig. 4 shows the jump spark connections. Contact is made in the low-tension distributor. This connects the source of electrical energy to the primary coil, the

vibrator contacts, distributor and to ground and back to the source, completing the primary circuit. When the primary core is sufficiently magnetized, the vibrator contacts are opened, breaking the primary circuit and inducing in the secondary winding a very high voltage kick. The continued vibrations will send a shower of sparks across the spark plug gap as long as the low-tension distributor contact remains closed. The portion of the distributor supporting the contacts is constructed so as it may be turned at different angles about the shaft, thus changing the position of ignition with reference to the engine cylinder. This gives the timing range necessary for setting the spark to the most efficient position.

At this stage of the development the magneto was beginning to be used extensively in addition to the batteries. The necessary renewals of dry cells when used continually became objectionable and so the batteries were only used at low speed and when starting the engine, as the magneto did not generate enough current when running at low speed to supply the ignition. A switch was arranged on the dash to change it from one to the other as desired by the driver. Still the ignition was not right and the rapid improvements in the engine

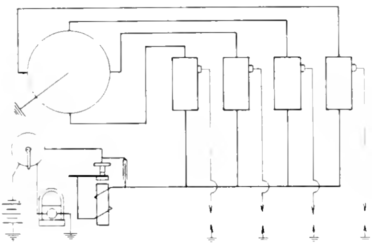


FIG. 5—MASTER VIBRATOR SYSTEM

showed all the more that further improvement was necessary. It was found impossible to adjust the different vibrators to get smooth firing, especially at the higher speeds, and the tendency of engine design leaned toward the higher-speed engine. The trouble was in the coil and the vibrator. The coil core took a certain length of time to magnetize. One vibrator would open the contacts sooner than the other. This would cause an uneven running of the engine, and the effect was modified for high speeds.

The Master Vibrator, which controlled all the coils from the one vibrator, came next. It gave a uniformity in the time of firing and the engine would operate very smoothly when the proper adjustment of this one vibrator was obtained. This scheme is shown in Fig. 5. Experimenting with the master vibrator system brought about still another improvement. Making the magnetic circuit of the master vibrator of slower magnetizing material as compared with the primary core, the primary core could be totally magnetized before the vibrator contact would open. This gave the first spark a very large amount of energy, and it was noticed that this spark alone was sufficient to ignite the charge, and by eliminating the following sparks no perceptible loss of power was noticed in the engine.

The Single Spark system of ignition made use of an interrupter instead of the master vibrator. This was placed on the end of the magneto and a cam on the same shaft opened the interrupter contact the same as did the

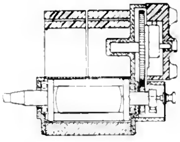


FIG. 6

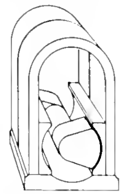


FIG. 7

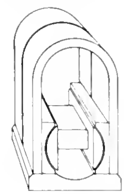


FIG. 8

Fig. 6—Low-tension magneto.
Fig. 7—Inductor type armature.
Fig. 8—Shuttle type armature.

master vibrator, except that it was opened without any lag and occurred at exactly the same angle regardless of the engine speed. The interrupter could also be adjusted for advance and retard position. The low-tension distributor at this stage practically disappeared, and in its place came the high-tension distributor, which eliminated all but one coil. The interrupter and high-tension distributor were assembled on the magneto, which now took the lead, Fig. 6. The commutator and brushes were discarded and the alternating current was used, arranged so that the time of break in the interrupter occurred at the peak of the wave. The magneto armatures were of two different types—the inductor type, Fig. 7, and the shuttle type, Fig. 8. The connections were generally by two different methods, Figs. 9 and 10.

The High-Tension Magneto was the last important improvement in magneto design, being connected as shown in Fig. 11. Winding the secondary coil on the magneto armature was an improvement over the low-tension magneto in three ways—first, it eliminated the primary winding and core (as the magneto winding performed its functions), therefore eliminating the losses in these parts; second, the generation of energy in the

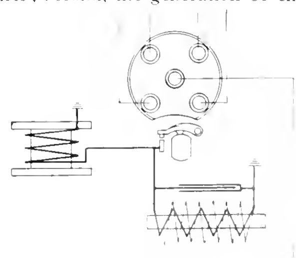


FIG. 9—CLOSED CIRCUIT TYPE MAGNETO

secondary winding within itself by cutting the lines of force in the magnetic field added to the efficiency; third, it allowed building an interrupter in which the contact pressure increased with increasing speed.

Battery Distributor Ignition—The appearance of electric starting and lighting on the automobile has

brought about more possibilities in the improvement of the ignition apparatus. The storage battery, used in connection with the starting and lighting systems makes a comparatively large supply of electrical energy from which to take the ignition current. The connections for

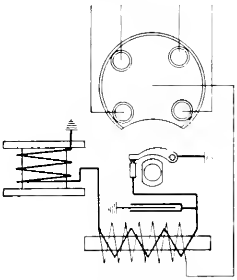


FIG. 10—OPEN CIRCUIT TYPE MAGNETO

the battery ignition system are shown in Fig. 12. The high-tension distributor and interrupter are mounted in the same unit and stand in a vertical position, driven directly from a shaft on the engine or from the lighting generator shaft. It rotates at one-half engine speed, and since the interrupter cam and moving part of the distributor are located on the same shaft, the cam will have as many lifts as the number of engine cylinders. The general appearance of such a unit is shown in Fig. 13. The coil condenser and ballast resistance are usually assembled together in a 2.5 to 3 inch tube and mounted on the dash or on the engine near the distributor. The switch is sometimes mounted on the end of the coil, and in this case the coil must be mounted on the dash in such a manner as to allow the switch to become flush on the dash or cowl-board, but usually the switch is separated to enable mounting it in the most accessible place for the driver.

High-tension distributors are made in two forms:—first, with a brush to carry the current from the rotating member to the proper terminal on the fixed member or

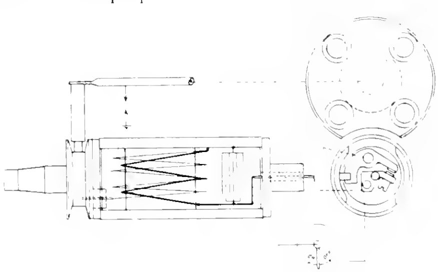


FIG. 11—HIGH-TENSION MAGNETO CONNECTIONS

distributor cap; second, instead of the brush a metal part of the rotating member has a small clearance between it and the terminal on the distributor cap. The current will jump this gap and carry the spark to the proper cylinder. It is, however, hard to determine which is the better principle, as the advantages of one are offset by those of the other. For instance, the disadvantage of the distributor without brushes is the energy spent in spanning the gap. This is equally balanced by the wear on the brush and brush track, the greater number of parts and the leakague due to carbon dust from the brushes upon the insulated parts.

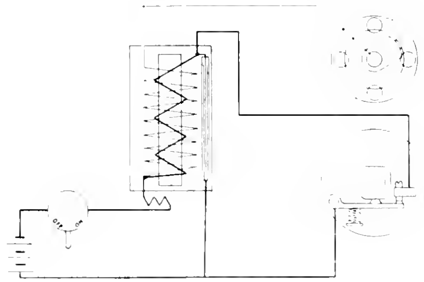


FIG. 12—BATTERY DISTRIBUTOR SYSTEM

The interrupter is made in four different constructions, each one having their good and bad features. To understand the reason for the different types of interrupters it is necessary to understand the characteristics of the battery ignition system. To get complete magnetizing of the induction coil iron core, a certain time of contact is necessary in the interrupter. Less time will allow the interruption of the circuit to occur before the core has taken in its rated capacity of energy and the igniting spark will be correspondingly weak. A larger time of contact will be energy wasted in the coil, which will appear as heat. Also for best results it is necessary for the firing of the charge as described above to occur earlier for higher speeds and richer mixtures. Stopping an engine with the contacts in closed position and a switch closed will be liable to discharge the battery or burn out some portion of the ignition circuit if left long enough. Hence an ideal interrupter would first be simple in construction and reliable; second, have

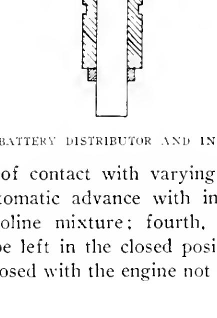


FIG. 13—BATTERY DISTRIBUTOR AND INTERRUPTER

an equal time of contact with varying engine speeds; third, have automatic advance with increasing engine speed and gasoline mixture; fourth, have a contact which cannot be left in the closed position in case the switch is left closed with the engine not running.

The most commonly used interrupters of the present date are shown in Figs. 14, 15, 16 and 17, of which Fig. 14 is the most simple and reliable construction, and for that reason is greatly used. However, the time of contact varies inversely with increasing engine speed, and it is found necessary to make the moving parts light in order to keep an equal angle of contact with the increasing speed. If the lever is unable to follow the cam on the descending side there will be additional time loss added to the actual calculated decrease in time of contact. With this interrupter the ignition spark will be found to decrease with increasing speed. This interrupter causes a straight line firing, i. e., there is no lag in the position of firing, as there is with the other types as shown above. The interrupter shown in Fig. 15 is very commonly used. This interrupter has a slight increase in angle of contact with increasing engine speed; also a lag in the firing position. The increased time of contact will be in proportion to the weight of the lever and the quickness of the contact spring. The break is made on the descending side of the cam lift instead of on the ascending side as in Fig. 14. In operation the lever is raised by the cam lift, and if the action of the spring is quick enough to follow the motion of the lever when going up the lift of the cam contact will then be

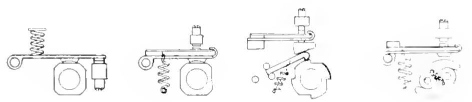


FIG. 14 FIG. 15 FIG. 16 FIG. 17

Figs. 14 to 17—Different types of interrupters.

made on a straight line position (not the firing position). It is then necessary for the lever spring to cause the lever to follow the descending side of the cam. Due to the weight and the momentum gained in the lever on the upward motion at high speed the spring is unable to move the lever quick enough to eliminate the lag in the firing position of the interrupter. With this type of interrupter a wider angle of timing range is provided, and in some cases automatic advance is given in addition to the manual advance to make up for the lag of the interrupter. In Fig. 16 is shown a type of interrupter which accomplishes two of the requirements of an ideal interrupter, equal time of contact and the impossibility of not stopping on contact, but has the lag as mentioned above, and also is of a delicate and complicated construction. The total angle of contact in this type of interrupter is all lag, and since the time of contact remains constant the angle of contact increases with increasing speed, and likewise the angle of lag increases with the increasing speed. If the engine is set to fire on dead center (not considering the lag in the motion of the pawl) contact will always be made at dead center position of the engine, but the angle at which the break will occur will depend on the speed of the engine and the time of contact of the interrupter. Hence at very low engine speeds the angle of contact becomes infinitely small, and with increasing speeds it increases very rapidly. Thus the time of contact is limited to a very small amount, to keep a minimum lag. This necessitates building a coil of the quick magnetizing type and reducing the resist-

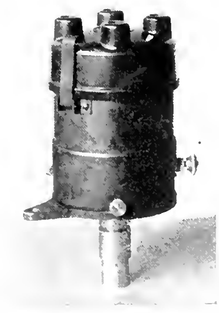


FIG. 18—WESTINGHOUSE VERTICAL IGNITION UNIT FOR MOUNTING DIRECTLY ON A FOUR-CYLINDER ENGINE

ance of the primary circuit as far as possible to allow the coil to store enough energy in the short length of time provided.

The interrupter shown in Fig. 17 possesses to some extent three of the requirements of an ideal interrupter—increasing angle of contact with increasing speed, simple construction and automatic advance—but retains the possibility of stopping with the circuits closed. This possibility is much less than is found in the types in Figs. 14 and 15, since the angle of contact is very small at low engine speed, and thus there is a greater chance of stopping in the open position.

The ignition coils are made up of one general type, a primary coil and core, and secondary connected as in Fig. 12. The ballast resistance is connected in series with the primary coil, and its effect on the system is to equalize the high and low speed spark energy.

The switches are made to accomplish different features, such as reversing the direction of current through the interrupter alternately as they are turned off and on again to reduce the building up and pitting of the inter-

FIG. 19—DETAILS OF IGNITION UNIT

rupter contacts. Also they can be built so as to open the circuit automatically in case the ignition switch is forgotten in the *on* position when the engine is stopped with the interrupter contacts closed. It is also found to be an advantage to equip the switch with a locking device to protect the car from theft.

Promoting the Sale of Electric Delivery Wagons

THE merits of the electric delivery wagon for the distribution of goods in thickly populated districts have been recognized for some time, particularly by some of the larger merchants and express companies who employ quantities of vehicles, and obviously have given more consideration to this matter than the small merchant. This had led to the adoption by many large merchants and transportation companies of fleets of electric vehicles, which are increased from year to year with the expansion of business, and it is a significant fact that during the last few years a large share of electric delivery trucks produced were sold to previous users. This indicates not only the economy and satisfaction which results from their use, but indicates further the lack of knowledge by those companies who require only a few wagons of the advantages of the electric wagons in fulfilling the operating conditions.

The small merchant who owns one or two horse-drawn wagons seldom takes the trouble to determine the cost of distributing his goods, segregating these from his general operating expenses and analyzing them item by item; nor does he often consider the building up of his business through better delivery service. He is ordinarily the most difficult man for the electric truck manufacturer to approach, because he is less systematic and analytical in his methods, and consequently less open to conviction that an outlay in machinery for efficient delivery will result in a net saving in operating expenses.

Bearing in mind these conditions, the recent campaign of the Ward Motor Vehicle Company, of Mount Vernon, New York, in the exploitation of the "Ward Special"—a 750 pound capacity electric delivery wagon—is exceedingly interesting, because the campaign was primarily aimed at the small merchant located in New York, Brooklyn and adjacent cities. Moreover, it was conducted upon lines which indicated that a very careful and thorough study had been made of the conditions confronting the small merchant located in these districts in the distribution of his sales. This delivery wagon has been designed especially for this class of service; it has been standardized as to construction, and the same scheduled manufacturing process is followed as that adopted by the large builders of gasoline cars.

General Scheme—The special sales campaign lasted during the months of October and November, ending on December 4, 1915. It was a co-operative campaign in every sense of the word. It was timed to occur during the period when merchants give careful consideration to matters of distribution and usually purchase horses for fall and winter service.

Terms—The electric wagon, which sells for $875 (battery upon a rental basis, as described later), was offered to the merchant upon an installment plan of payment approximately in line with the following figures:—

1—Upon signing of contract, five percent.

2—Upon delivery of electric wagon, 35 percent.

3—Monthly thereafter for a period of twelve months, five percent per month with interest.

Battery-Service Plan—The vehicle is delivered to the purchaser completely equipped with 65 cells of GA Edison storage battery, but the battery remains the property of the battery manufacturer. For the first year the purchaser has free use of the battery for a vehicle mileage not exceeding 625 miles in any one month, and should the vehicle mileage exceed 625 miles in any one month the purchaser pays to the battery manufacturer a sum at the rate of 1.75 cents per mile for each excess mile. After the first year the purchaser pays to the battery manufacturer a rental charge of $10.50 per month, with the same excess mileage charge as that mentioned. Thus battery service is provided by the battery manufacturer for a definite monthly charge. If desired, the battery may be purchased outright by the vehicle owner. The owner of the car pays for the power used to charge the storage battery at the current rates and at such place as he may have the battery charged, and the cost of this power is not included in the rental charge for the storage battery. The wagon when delivered to the purchaser is equipped with an odometer, which is sealed by the battery manufacturer and read by his agent periodically to determine the basis for charge in excess of the mileage stipulated of 625 miles per month.

Publicity—Special bulletins describing the electric wagon were mailed to a large list of prospects. Bulletin board advertising and newspaper advertising were also employed.

Central Station Co-operation—Those central power stations in and about New York City joined with the vehicle manufacturer in financing and executing this publicity campaign, and also in finding and appealing to prospective purchasers.

Canvas—In general, the sales force of the central stations worked as the "first line of offense" and opened the way for the "heavy artillery," which consisted of the manufacturer's salesmen, who were ready with demonstration cars to substantiate statements made.

Advantages—The following quotation* outlines briefly the advantages to the customer of such service, being based upon an analysis of conditions in and about New York City:—"*1*—This vehicle can be stored and washed in fifty livery stables in New York City for $10 per month. *2*—For an average daily mileage of approximately 20 to 25 miles per day the current cost to the consumer will not exceed $10 per month. *3*—It costs less to keep the electric vehicle in tires than it does to keep a single horse in shoes for the same distance. *4*—From paragraphs *1* and *2* it is obvious that the customer can secure for $20 per month what now costs $28 to $30 per month, the latter being the cost of feed and care for his single horse outfit. *5*—The customer has

*From the *National Electric Light Bulletin* of November, 1915.

the advantage of a vehicle that is vastly more flexible in his service than is the single horse and wagon. In other words, this vehicle will fit into his 15 or 20 mile routes at costs which are lower than those of his horse equipment. Should a sudden demand require 40 or 50 miles per day in his delivery service, the car can instantly meet this condition with only a slight increase in cost to cover the extra wear on the tires and other parts."

A campaign such as this one holds out a number of points of interest to electric vehicle manufacturers, central stations and manufacturers of component parts of the electric vehicle. No one will admit that the last word has been said as to the best methods of marketing electric vehicles, and it is felt that in this campaign are the elements at least of a marked advance toward the upbuilding of the electric vehicle industry as a whole.

ENGINEERING NOTES

Increasing the Spark by Adding Resistance

Strictly speaking, it is impossible to increase the spark from a given coil by increasing the ohmic resistance in series with the primary. It is possible, however, to make a coil that with resistance in series will store energy more rapidly than another without resistance and so give a better spark when operating at such a speed as not to permit the current to reach a final value.

The equations of rise of current in such a coil are derived as follows:—

$E = iR + L\frac{di}{dt}$, where i = the instantaneous value of current, and iR and $L\frac{di}{dt}$ = the e.m.f. taken up by the resistance and the inductance, respectively.

$$\text{Then } i = \frac{E - L\frac{di}{dt}}{R} \text{ or } \frac{di}{E - iR} = \frac{dt}{L}$$

$$\text{and } \int_o^i \frac{di}{E - ir} = \int_o^t \frac{dt}{L}, \text{ or, integrating,}$$

$$-\frac{I}{R}\log(E - iR)\Big]_o^i = \frac{t}{L}\Big]_o^t \text{ and taking limits}$$

$$i = \frac{E}{R}\left(I - \mathcal{E}^{-\frac{Rt}{L}}\right),$$

$$\text{but } \frac{E}{R} = \text{final value of current} = I.$$

The instantaneous value of current is therefore at all times equal to the final value minus a variable quantity $I\mathcal{E}^{-\frac{Rt}{L}}$. Taking a value of $t = \frac{L}{R}$, the quantity $I\mathcal{E}^{-\frac{Rt}{L}}$ becomes $I\frac{I}{\mathcal{E}}$, and as $\mathcal{E}$ = 2.718+ this quantity becomes 0.368 I and at the chosen value of t, $i = I - 0.368\,I = 0.632\,I$. This value for $t = \frac{L}{R}$ at which the rising current reaches 0.632 of its final value is commonly

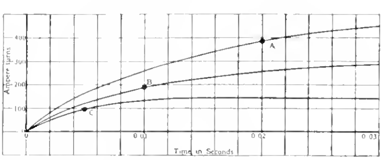


FIG. 1—RISE OF CURRENT IN THE PRIMARY OF AN INDUCTION COIL OF 100 TURNS

In A—L = 0.02 henry; R = 1 ohm; ballast = 0; amperes = 6.
In B—L = 0.02 henry; R = 1 ohm; ballast = 1 ohm; amperes = 3.
In C—L = 0.02 henry; R = 1 ohm; ballast = 3 ohms; amperes = 1.5

known as the time constant of the coil and gives a convenient measure of the period of rise of current in different coils.

For convenience of comparison the curves in Figs. 1 to 3 are plotted in ampere turns instead of amperes, as the secondary spark is directly related to primary ampere turns if the rest of the coil is unchanged. The curves in Fig. 1 show the rise of ampere turns in a coil of 100 turns having an inductance of 0.02 henry and a resistance in the coil of 0.1 ohm. The coil is supplied with current from a six-volt source. Curve A gives the current with no resistance in series and a final value I of six amperes or 600 ampere turns. Curve B gives the current with 0.1 ohms in series and a final value of three amperes or 300

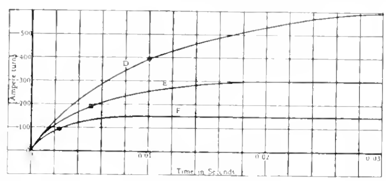


FIG. 2—RISE OF CURRENT IN THE PRIMARY OF AN INDUCTION COIL OF 50 TURNS

In D—L = 0.005 henry; R = 0.25 ohm; ballast = 0.25 ohm; amperes = 12.
In E—L = 0.005 henry; R = 0.25 ohm; ballast = 0.75 ohm; amperes = 6.
In F—L = 0.005 henry; R = 0.25 ohm; ballast = 1.75 ohm; amperes = 3

ampere turns. Curve C gives the current with 3 ohms in series and a final value of 1.5 amperes or 150 ampere turns. While the time constant is reduced by the adding of resistance from 0.02 seconds to 0.01 seconds and to 0.005 seconds, the ampere turns, and consequently the spark, are both reduced also.

Curves D, E and F, Fig. 2, cover the rise of current in a 50 turn coil of the same general dimensions, but of course having L one-fourth as great, or 0.005 henry, and the resistance also one-fourth as great, or 0.25 ohm. Obviously, reducing the number of turns has not changed the time constant of the coil itself, as the L and R change in the same ratio. The use of a larger current, however, with part of the voltage taken up in resistance, permits energy to be stored more rapidly.

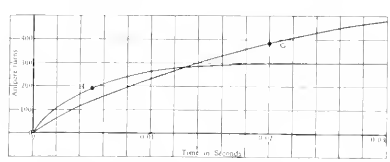


FIG. 3—COMPARATIVE CURRENT RISE IN COILS OF 100 AND 50 TURNS AND EQUAL CURRENT

In G (100 turns)—L = 0.02 henry; R = 1 ohm; ballast = 0; amperes = 6.
In H (50 turns)—L = 0.005 henry; R = 0.25 ohm; ballast = 0.75 ohm; amp. = 3
The heavy dot shows the point where t = L ÷ R and the current equals 0.66 of the final value.

Curves G and H, Fig. 3, show that even with the same amperes from the battery there may for a short period be a more rapid storage of energy in a 50 turn coil with ballast of 0.75 ohm than in a 100 turn coil with no ballast. It is only during a very short interval of time after closing the circuit that this is true.

R. P. JACKSON

The Journal Question Box

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1265—Induced Current—A two-wire No. 10 copper line follows a 60 000 volt, three-phase, 60 cycle transmission line on the same poles and about ten feet below it. Would it be possible to build a small alternating-current generator that would stay in step with the induced current across these two wires, when direct connected to a synchronous motor (or through gears to give the proper speed), which got its power from the 60 000 volt line through the necessary transformers? Would loading the power line affect this wave form any? H. R. K. (CALIF.)

The induced voltage in the No. 10 line is of the same frequency as that of the transmission line which produces the disturbance. Therefore, an alternating-current generator would stay in step with it, if driven from a synchronous motor supplied by the transmission line. The induced voltage may be caused either by electrostatic or electromagnetic induction, or by both. If the former, the wave form is determined solely by the wave form of the transmission line potential and the voltage is not affected either in amount or wave form by changes in load on the power line except as such changes affect the voltage of the power line. If the effect is due to electromagnetic induction its wave form is determined solely by that of the power line current, and its value will be proportional to the power line current. The question seems to indicate that it is desired to offset or neutralize the induced voltage in the No. 10 line. This can be best accomplished by proper transpositions of the line so that the average position of each of the wires with respect to the power lines will be the same. It is also essential that neither of the wires be grounded, as in such a case current will tend to flow to ground from both of the wires in case of induced voltage appearing between the line and ground. This would, of course, necessitate the flow of current from the ungrounded to the grounded wire through whatever apparatus is connected between the two. A. W. C.

1266—Amount of Motor Iron—Will adding more iron to a motor or generator affect the output of the machine and in what way? Can too much iron be put in a magnetic circuit? L. B. G. (ILL.)

The torque of a motor or the counter torque of a generator, which is a measure of its output, is proportional to the strength of the magnetic field and the current flowing in the conductors which are located in that field. Increasing either one of these factors will increase the output, everything else remaining the same. Increasing the actual amount of iron in the machine will permit increasing the magnetic field, and from that standpoint alone means increasing the output. There is a limit to this which comes when the iron is no longer worked economically. This means that a certain flux density or magnetic saturation in the iron will give the best results for a given design. If the iron in the machine is increased so that the magnetic saturation falls below the point of maximum efficiency it is no longer of advantage to increase it beyond that point. Practically the usual way of increasing the iron is in the axial direction along the shaft, and increasing this dimension introduces mechanical considerations, such as distance between bearings and size of shaft, which have a determining influence on this feature. A. M. D.

1267—Effect of Field Excitation Upon Rotary Converter Load—What effect, if any, has a change in the field excitation upon the direct-current circuit of a rotary converter, (a) when running alone, (b) when in parallel with other machines? How is the alternating-current circuit affected? How may the load be shifted from one rotary to another when the machines are in parallel, on the direct-current side? H. W. M. (MINN.)

A rotary converter requires a certain definite amount of flux passing through its magnetic circuit. If the excitation to produce this flux is not provided on the field poles it must come automatically from the armature. Hence, when the field excitation is varied, the armature automatically takes a lagging or leading current from the line, the magnetizing effect of which compensates for the change made in the field excitation. This lagging or leading current flowing through the reactance of the circuit produces a reduction or increase in the alternating-current voltage, which is at once evidenced by a corresponding change in the direct-current voltage. Any change in field excitation, therefore, produces an actual change in the direct-current voltage delivered by the converter when running alone and tends to produce such a change of voltage when running in parallel with other machines. In the latter case, it causes such a shifting of the load as will compensate for the variation in alternating-current voltage by the resulting variation in the internal drops. J. L. Y.

1268—Motor Operation—(a) With a three-phase, delta-connected secondary transformer connected to a three-phase motor, what changed conditions occur as will effect power-factor, current per phase, voltage on the remaining leads and efficiency when a fuse blows in either the transformer primary or secondary? (b) What would be the result of running a 25 cycle motor on a 60 cycle circuit, or vice versa? What elements enter into the design of an induction motor, especially in regard to the importance of frequency? (c) How would you detect a reversed coil in a three-phase stator? L. B. G. (ILL.)

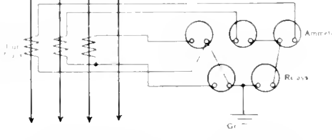
(a) Blowing one fuse in either the primary or secondary of the transformer will leave the motor operating single phase. It will continue to run, if the load is not too great, with a current in the active phase about 200 percent of what it was when running three-phase. The maximum torque will be 35 to 40 percent of its value as a three-phase motor. It would, of course, have no starting torque if allowed to come to rest. (b) If the voltage on the machine is varied exactly in the same way and by the same amount as the frequency the magnetic induction in the iron and the total magnetic field in the motor will remain the same. This means that with the same armature currents the torque will remain the same and the r.p.m. and horse power will vary directly as the frequency. (See articles by Mr. G. B. Werner on "Variations in Industrial Motor Performance with Variations in Voltage and Frequency," in the JOURNAL, Vol. III, p. 400, and by Mr. R. E. Hellmund on "Standard Apparatus on Special Frequencies," Vol. VII, p. 680). The limitations on this method of operation are the highest r.p.m. which the rotor will stand mechanically, and the highest voltage which the insulation will safely stand. The influence of frequency is felt most directly on the speed since

$$\text{synchronous speed} = \frac{\text{Alts per minute}}{\text{No. of poles}}.$$

Therefore, the number of poles must be chosen so as to give the speed desired. (c) A reversed coil may be suspected if the currents in the phases are unbalanced without any apparent reason or if there is pronounced mechanical vibration of high frequency. It may be detected either by inspection of the actual physical connections or by exploring the inside of the stator bore with a small compass. To make the latter possible the rotor should be removed from the stator and a low direct-current voltage, say 10 percent of normal, impressed on the stator windings. If the compass be then held close to the inside bore of the stator laminations and passed slowly around in the direction of rotation of the rotor, the compass needle will swing through 180 degrees in passing from a north to a south pole and return on passing from south to north. As it passes under the defective or reversed coil a momentary fluctuation of the needle will indicate the difficulty. A. M. D.

CORRECTIONS

Fig. 14, p. 525, of the JOURNAL for November, 1915, should appear as below:—



On p. 557, Dec., '15, near the bottom of the second column, "tan^{-2}" should read "tan^{-1}."

ECONOMIC ADVANTAGES OF PHILADELPHIA THIN PLATE BATTERIES IN TRUCK SERVICE

JAMES M. SKINNER
Engineer of the Philadelphia Storage Battery Company

The Philadelphia thin plate battery has now completed its sixth year of successful operation in electric truck service. Put on the market in 1909, the type WT has been improved and perfected, year by year, being succeeded in 1912 by the lighter, higher capacity WTX, and reaching its highest development in 1915 in a still lighter, still higher capacity type, the WTXI. The WT quickly displaced the older, heavier type of plates which had been standard prior to 1909, the WTX displaced the WT, and the WTXI in turn is now engaged in displacing the WTX.

The first big advantage of Philadelphia thin plate batteries is that they are "oversize." The trend of the times is toward "oversize" equipment. We use tungsten lamps, not of the same candle-power as the carbon lamps of a few years ago, but of higher candle-power, electing to obtain more light rather than lower cost; in all directions we demand a bigger margin than heretofore Philadelphia thin plates meet this demand as applied to electric trucks. Users want more mileage than formerly. Philadelphia thin plates have increased the daily mileage of electric trucks from 50 to 100 percent. Philadelphia batteries maintain higher car speed. An electric pleasure car equipped with a standard Philadelphia WTX battery made the trip from Philadelphia to Boston at an average speed greater than 20 miles per hour.

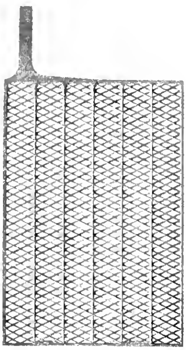


FIG. 1—DIAMOND GRID USED IN PHILADELPHIA THIN PLATES

At first glance it might appear that the demand for "oversize" equipment is unwarranted, and that people are buying something that they cannot use. The electric truck of a decade back had neither the mileage nor the speed of the present-day thin plate equipped car, yet it went about doing its work and apparently gave satisfaction. Of what use then is the increased mileage and speed of the present-day car? The answer is that greater mileage and higher speed have added immensely to the radius of operation and the flexibility and the reliability of the electric, and have decreased battery maintenance costs. They have brought a larger field of operation within the capability of the electric and have reduced the operating expense. If the daily mileage required is small, a thin plate battery need only be charged once every two or three days. If snow or bad roads cause excessively high power consumption, the "oversize" characteristic of the thin plate enables the car to cover its usual route without difficulty. If conditions change and longer distances must be traveled per day, the battery is ready and able to meet the demand. Even if the mileage required is 25 or 30 percent greater than can be supplied by the normal capacity of the battery, 25 or 30 percent additional capacity can be obtained from the battery by means of an hours' boost at noon or a few minutes' boost each time the car returns to the loading station. By simply varying the amount of charge given to the "oversize" thin plate battery the car automatically takes care of short routes and long, good weather and bad, dull seasons and rush times.

This means when reduced to concrete figures, that the mileage capacity of a one or two-ton electric ten years ago was 30-35 miles. The first Philadelphia thin plate, the WT, increased this to 45-50 miles. The WTXI will give 55-65 miles, and with the aid of a little boosting, 75-80 miles per day. In other words, the mileage capacity of the present-day thin plate equipped electric is double that of the electric of 10 years ago. It may be shifted on a moment's notice from a 20 to a 50 or 60 mile route. The big "oversize" thin plate battery makes it adaptable for every emergency of city delivery.

The second advantage of the Philadelphia thin plate battery is moderate price. The initial price is the lowest possible for a high quality battery and the renewal price is approximately only 65 percent of the original price. The low price reduces the investment and brings the cost of the car within the range of the small merchant. Low initial battery cost is also of importance to the user of a fleet of trucks. A saving of from $500 to $1500 per car on the price of the battery does not seem so much in itself, but when multiplied by the number of batteries used in a fleet of 20 trucks it amounts to the respectable sum of from $10 000 to $30 000. The low initial price of the Philadelphia thin plate batteries is of value to both the large and small user.

The third advantage of Philadelphia thin plate batteries is low operating and maintenance cost. This is the product of many factors. A big factor is the "Diamond Grid." Philadelphia thin plates are all pasted upon the diamond grid. The diamond grid is built like a bridge truss with members so interlacing and having such mechanical strength that buckling is practically impossible. The interlacing of the members, moreover, provides another exclusive Philadelphia feature. The active material is actually locked between the members on the opposite sides of the plate and cannot jar loose and fall out.

Another factor is the Philadelphia long-life paste composition, developed especially for thin plates, in combination with the Philadelphia hard wood separator. It has been argued that it is useless to use exceptionally long-life plates in storage batteries, since exceptionally long life could not be realized because of premature failure of the wood separators. This argument has force when applied to batteries containing ordinary soft wood separators. The life of the plates in such batteries is often limited by the shorter life of the wood separators. Philadelphia hard wood long-life separators are an important feature in Philadelphia thin plate batteries because they permit the realization of maximum plate life.

Still another factor in low operating cost is the high rib high quality rubber jars. The high ribs provide sufficient space underneath the plate to accommodate all of the sediment accumulated during the life of the battery and no expensive, time-consuming cleanings are required. The high quality means more new rubber in the jars, and adds to their cost, but it practically eliminates jar breakage. All Philadelphia thin plate batteries are assembled in high rib, thick walled, high quality jars.

The high efficiency of Philadelphia thin plate batteries is another factor which reduces the operating cost. The Philadelphia thin plate battery requires less current per car-mile than any other battery on the market. The alkali battery, as is shown by records of actual operation, requires at least 40 percent more charging current. This item alone represents a saving in using the Philadelphia thin plate of from $50 to $300 per year, depending on the size of the car, the miles run and the cost per unit of charging current.

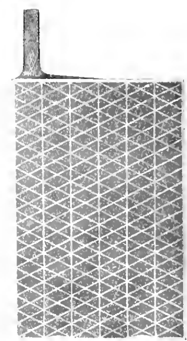


FIG. 2—THE FINISHED PLATE, SHOWING TRUSS CONSTRUCTION THAT INSURES RIGIDITY

Another factor in the low operating cost of Philadelphia thin plate batteries is the small amount of regular daily attention they require. Regular charging, systematized to avoid gassing and heating, and periodic flushing with pure water constitute the sum total of the attention required. In fact, experience has shown that the less attention given, beyond ordinary cleanliness, systematic charging and regular flushing, the better the results obtained. There are on the market today many forms of charging apparatus, low in cost, efficient and absolutely reliable, which automatically give the battery a proper charge with no attention or adjustment whatever on the part of the operator. Such apparatus to date has found its largest application in the electric pleasure vehicle field, but there is no good reason why it should not be just as widely applied in commercial battery charging. Philadelphia engineers are always ready to co-operate with car owners in the selection of operating apparatus suitable to their requirements.

The final factor tending toward long life, and therefore lower maintenance

cost from Philadelphia thin plate batteries, is their "oversize" characteristic. Thick plate and other low capacity batteries in electric trucks are often overworked. They are overdischarged and overcharged. In order to give maximum life a battery should not be overdischarged nor overcharged. The two factors tending to wear out a battery are gassing and the chemical combination of the active material with the acid of the electrolyte. Gassing is a product of charging; the combination of the active material with the electrolyte is the essence of discharging. Gassing represents waste. As long as the battery is capable of absorbing all the charging current no gas can be generated. It is only toward the end of a charge, when the amount of discharged material is small, that there is much danger of gassing. At the beginning of charge the large amount of discharged active material in the plates enables the battery to take a very high rate of current without gassing. As the charge progresses the amount of discharged material decreases, and if the current rate is not reduced there may be more than can be absorbed, and the execss will be dissipated in producing gas. The gas bubbling out from the pores of the plates exerts a washing action on the active material and causes some of it to loosen from the plate and fall to the bottom of the cell. Here is

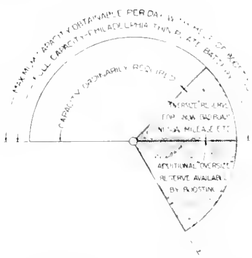


FIG. 3—DIAGRAM SHOWING CAPACITY RANGE OF PHILADELPHIA THIN PLATE BATTERIES

where the "oversize" characteristic of the thin plate comes in. The nearer to a fully charged condition that a battery approaches the heavier the gassing. Fully one-half the wear due to gassing occurs during the last five or ten percent of the charge. Therefore it is desirable to reduce to a minimum the amount of charging given a nearly fully charged battery. Since the capacity of a thin plate battery is greater than is usually needed, except for emergency, it is possible and desirable not to charge the battery fully, except once every week or two, but to bring it up ordinarily to say only 90 or 95 percent full charge, thus eliminating on all but a few charges the last five or ten percent of the charge which causes the greatest wear on the plates.

Just as wear due to charging becomes more pronounced the nearer a battery approaches a fully charged condition, so the wear due to discharging becomes more pronounced the nearer a battery reaches a fully discharged condition. Discharging tends to fill up the pores of a plate by the formation in the plate of lead sulphate. This is a perfectly normal condition. Lead sulphate is simply discharged active material. Unless lead sulphate forms there can be no discharge. Now lead sulphate occupies more space than did the charged active material, and it is a characteristic of a well-designed plate that sufficient porosity has been provided within the plate to accommodate, without excessive strain, all the lead sulphate which forms on an ordinary discharge. It is inevitable, however, that discharging should cause some dislodgement of the active material. The more completely discharged a plate becomes the more the pores become filled with sulphate, the less space there is for the formation of more sulphate and the more likely it is that surface particles will be pushed off by the sulphate accumulating behind them and unable to find pore space in which to grow. It is just here that too hard plates fail. They have very little porosity. The amount of sulphate necessary to fill the pores is small, less than is likely to be produced on even a moderate discharge, consequently the strain imposed upon the plate by discharging is very great and either material will be dislodged or the plate will tend to buckle under the strain. Very hard, dense plates may be well adapted to withstand wear due to charging, but they are ill adapted to withstand much discharging.

Philadelphia thin plates are built to withstand discharging wear as well as charging wear. Porosity is not sacrificed to obtain maximum hardness. There are enough pores to accommodate all the sulphate which is formed during discharge, so that even under conditions of heavy discharge they wear slowly. But even this slow wear is greatly diminished by their "oversize" characteristic. To obtain all the mileage desired it is rarely necessary to discharge them to more than three-fourths of their full capacity. Experiments have shown that the life of the battery in days is greatly increased if it is seldom discharged to its maximum capacity. Maximum life in days and miles is obtained when a batterly is regularly recharged after about 80 percent of its capacity has been used. Charging before 80 percent has been used increases the wear due to charging unless exceptional care is taken to eliminate gassing. Using more than 80 percent of the capacity before recharging emphasizes the wear due to discharging. The "oversize" characteristic of the Philadelphia thin plate makes it possible to operate a Philadelphia thin plate battery on 90-95 percent charges and 80 percent discharges and thus obtain maximum life.

In carrying out this procedure it must not be forgotten that a full charge followed by an overcharge at a very low current rate is desirable once every week or two. The slight daily undercharging leaves in the plates a small amount of discharged material, which tends in time to harden to an undesirable extent. The weekly or bi-weekly overcharges convert this discharged material to charged material at regular intervals, thus periodically bringing the plates up to their maximum capacity and keeping the battery in the best operating condition. Complete information as to the details of operation will be found in the instruction book published by the Philadelphia Storage Battery Company.

The foregoing facts have an important bearing on the subject of boosting. In hard service, where great mileage is required, it is always better to boost than to discharge a battery to its fullest extent. The reason for this is not hard to perceive. Too full discharges cause excessive wear. Charging also causes wear, but there should be very little wear on a boost which follows the very simple instructions given in the booklet on "Boosting," issued by the Philadelphia Storage Battery Company. The current rates employed are high, it is true, but they come at a time when the battery is sufficiently discharged to stand high charging rates, and the boost is not continued up to the point of full charge, so that there should be very little, if any, gassing and, therefore, very little wear. Boosting causes a battery to work just where it works with least wear, namely, in between the extremes of full charge and full discharge. In heavy service boosting actually tends to increase the life of the battery and may be employed without hesitation.

To retard the wear on the plate, Philadelphia thin plate batteries are provided with finely perforated rubber sheets, which are placed against the positive plates. These sheets serve their purpose very well and the actual falling off from the plates of loosened material is greatly retarded. Attempts have been made at various times to extend this protection by further enclosing the positive plates, as by envelopes or otherwise, but these have proven unsatisfactory in that they do not greatly increase the life

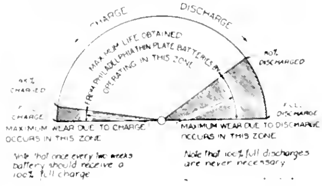


FIG. 4—DIAGRAM ILLUSTRATING HOW OVERSIZE CAPACITY INSURES AGAINST WEAR IN SERVICE

of the plates beyond that obtainable by the finely perforated sheets, and they do largely increase the cost, weight and space necessary for a given capacity, and entirely eliminate the important "oversize" characteristic.

Summing up, the economic advantages of Philadelphia thin plate batteries are three:—

1—They are "oversize" batteries.

2—Their price is moderate.

3—The cost of operation is low.

Due to their "oversize" they are prepared for any service, easy or hard. They meet equally well the moderate mileage of dull seasons and the greater mileage of rush times. They are able to cope with the increased demands imposed upon them by snow and bad roads without reduction of the usual route. They possess to the highest degree the quality of adapting themselves to the demands of the service.

The moderate price of Philadelphia thin plate batteries renders it unnecessary to tie up excessive amounts of capital in the transportation department, and the low operating cost reduces to a minimum the monthly expenses. The Philadelphia thin plate battery embodies to the highest degree the ability to meet the requirements of any service at the lowest possible cost.

PERSONALS

Mr. Edward N. Lake, formerly in charge of the Chicago office of the Stone & Webster Engineering Corporation, has become a partner in the Krehbiel Company, engineers and constructors, with offices in the Marquette Building, Chicago. Mr. Lake has made electricity and its commercial applications his specialty. Mr. Lake has been connected with the Arnold Company, Bion J. Arnold, the Western Electric Company, Chicago Edison Company and Board of Supervising Engineers. The Krehbiel Company is doing in smaller units the same kind of work that Stone & Webster, H. M. Byllesby & Co. and J. G. White Company have done in terms of millions.

Mr. D. E. Parsons, until recently of the Pittsburgh office of the Westinghouse Electric & Mfg. Company, has been appointed general manager of the East St. Louis & Suburban Railway, and will take up his new work on January 1. Mr. Parsons entered the engineering apprenticeship course at East Pittsburgh in 1904. In 1906 he took up work in the sales department. Later he was in the export department and in 1908 went to the Fairmont, W. Va., branch office. For the past several years he has been in the railway and lighting department of the Pittsburgh office.

Mr. E. G. Connett, president of the International Railways Company, of Buffalo, N. Y., has been elected vice-president of the United Gas & Engineering Corporation, New York City.

Mr. Charles A. Stone, of Stone & Webster, Boston, Mass., has been elected president of the American International Corporation, which has been organized for the purpose of promoting American enterprise, industry and commerce in foreign lands. Mr. Stone will transfer his residence from Boston to New York City.

Mr. Albert D. Hart, of the general engineering division of the Westinghouse Electric & Mfg. Company, who has been president of the Westinghouse Club for 1915, has resigned to take a position with the Morgan Silver Plate Company at Winsted, Conn.

Mr. Bernard Lester has recently been appointed manager of the small motor section of the industrial department of the Westinghouse Electric & Mfg. Company.

Mr. A. P. M. Fleming, superintendent of the British Westinghouse works, Manchester, England, is in the United States making an investigation of American institutions organized to conduct industrial research. At present he is at the University of Illinois in consultation with Prof. E. B. Paine, head of the electrical engineering department.

Mr. Arthur W. Berresford, vice-president and general manager of the Cutler-Hammer Mfg. Company, was elected president of the Electrical Manufacturers' Club at its recent convention at Hot Springs, Va.

OBITUARY

William Andrew Conner, of Plainfield, N. J., died suddenly Monday, December 6, at his office in Perth Amboy, N. J. He was born in Baltimore, September 12, 1859, and began his business career in 1876, in Pittsburgh, in the oil refining business, in which he reached the position of assistant manager for the Standard Oil Company. In 1885 he took charge of the first plant built by the Standard Underground Cable Company in Pittsburgh, and from then to the time of his death he was the head of the manufacturing business of that company, including large plants in Pittsburgh, Pa.; Perth Amboy, N. J.; Oakland, Cal., and Hamilton, Canada. He was a director for ten years and first vice-president since 1909. He was also vice-president and director of the Standard Underground Cable Company of Canada, Ltd. Mr. Conner moved from Pittsburgh to Plainfield in 1904, where he had since resided.

Mr. James Mapes Dodge, chairman of the board of the Link-Belt Company, died at his home in Philadelphia, December 4, 1915. He was born June 30, 1852, at Waverly, N. J. Mr. Dodge spent three years at Cornell University and a year at Rutgers. After spending a short time at the Morgan Iron Works in New York City, he entered the shops of John Roach, the shipbuilder, at Chester, Pa., where his marked mechanical ability and ingenuity brought him rapid advancement. Shortly after the Centennial at Philadelphia in 1876 he went to Chicago. Here he formed the acquaintance of William D. Ewart, the inventor of the Ewart link-belting, and soon after joined hands with Mr. Ewart and his associates in the development of the chain business. He entered into partnership with Edward H. Burr under the firm name of Burr & Dodge, who represented in Philadelphia the Ewart Mfg. Company of Indianapolis—the original manufacturers of Ewart detachable link-belt—for the exploitation of the Ewart chain and its allied interests. Out of this partnership grew the Link-Belt Engineering Company, organized in 1888. He was elected president of the Link-Belt Company in 1892 and chairman of the board of directors when it was organized in 1906 through the merger of the allied companies—the Link-Belt Engineering Company, Philadelphia; the Link-Belt Machinery Company, Chicago, and the Ewart Mfg. Company, Indianapolis. Mr. Dodge was responsible for the design of the links and attachments in all of the various sizes of link-belting used today throughout the world, and owing to the excellence of his original designs they have not yet been improved upon.

A.E.R.A. MEETING

The seventh annual midyear meeting of the American Electric Railway Association is to be held in Chicago on February 4, 1916. It is planned to go over the discussion of two subjects, "Valuation" and "Rate of Return." The meeting will be held at the Congress Hotel.

A.S.M.E. ANNUAL MEETING

At the annual meeting of the American Society of Mechanical Engineers, Dr. John A. Brashear, of Pittsburgh, retiring president, delivered an address on "Science in Its Relation to Engineering." The officers elected for the ensuing year are:—President, D. S. Jacobs; vice-presidents, G. W. Dickie, Henry Hess, James E. Sague, W. B. Jackson, of Chicago; J. S. Bancroft of Philadelphia; Julian Kennedy, of Pittsburgh; treasurer, W. H. Wiley; secretary, Calvin W. Rice.

COMING CONVENTIONS OF A.I.E.E.

At the meeting of the board of directors of the American Institute of Electrical Engineers, held December 10, 1915, it was decided to hold the usual midwinter convention in New York City on February 8-9, 1916. At the same meeting a Pacific Coast convention was authorized to be held in Seattle, Wash., in 1916, under the auspices of the Seattle Section of the Institute. The programs of these conventions will be announced later.

NEW BOOKS

"Principles of Direct-Current Machines"—Alexander S. Langsdorf. 404 pages, 313 illustrations. Published by McGraw-Hill Book Company, New York City. Price $3.00.

This college textbook for junior and senior students in electrical engineering is devoted principally to fundamentals underlying the design and operation of various types of direct-current machines. Attention has been concentrated upon certain features. For example, Chapter III contains a full derivation of the rules governing armature windings; Chapters VI and VII also include a considerable amount of material on the operating characteristics of generators and motors, largely of a graphic character, including the use of three dimensional diagrams. An extensive treatment of commutation is given in Chapters VIII and IX. This is a subject which is not ordinarily gone into deeply with students. While calculus is used freely, the book is not especially of a mathematical nature. The illustrative drawings are apparently original and in some cases present facts in a rather unique form. Only a few illustrations of commercial apparatus are included.

"Specifications and Design of Dynamo-Electric Machinery"—Miles Walker. 648 pages, 533 illustrations. Published by Longmans, Green & Co. For sale by THE ELECTRIC JOURNAL. Price $10.00.

There have been numerous books published on the design of electrical apparatus, but the present one goes into the subject much more thoroughly than any the reviewer has had the opportunity of examining. The author has been for a number of years consulting designer to the British Westinghouse Company, as well as professor of electrical engineering at the Manchester (England) School of Technology. While written by an English author, the book applies almost as well to American practice, due to interchange of information as to the designs of the American and British companies. The designs are essentially practical, beginning with discussions on the magnetic and electric circuits. This book includes not only the theoretical design, but the specifications of worked-out designs. In the first part of the book a collection of simple rules are given for calculating the dimensions and quantities met in designing electric motors and generators. The method of designing armature coils and moulds for forming coils is gone into quite thoroughly with illustrations of armature coil moulds of various types. The properties of insulation and methods of insulating coils are then taken up, including examples of calculations as to space required for insulation. The subject of generator ventilation with special reference to turbo-generators is then discussed, with a thorough analysis of the method of predetermination of temperature rise, including the use of thermo-couples. Part II takes up the specification and the design to meet the specification. A specification for a 750 k.v.a., three-phase, engine-driven generator is given and analyzed thoroughly; also for a generator to be direct-connected to a gas engine; also for a water turbine-driven generator. Turbo-generators are then discussed and the specification and analysis of a 15 000 k.v.a., three-phase turbo-generator given in full. A section on induction motor design follows, in which various details are discussed, such as magnetizing current and short-circuit current by calculation from the design, etc. A specification for a 1500 horse-power induction motor is given in detail, also for other motors designed for various specific purposes. A chapter is devoted to continuous-current generators, also to rotary converters and phase advances. To those who desire to go into details of design from a practical and commercial standpoint, this work should be unusually valuable.

"The W-PVT Chart"—Merl R. Wolfard and Charles K. Carpenter; size 24x38 inches; price 50c. Also "Conversion Chart," by the same authors; size 12x34 inches; price 25c. Both charts published by John Wiley & Sons, New York.

These charts are published in advance of a book by the same authors on "Exponential Computation Charts for Engineers." The W-PVT Chart contains three distinct groups of straight-line curves combined into one chart. The first group in the P-V Quadrant gives volume-pressure relations of any gas or vapor which follows the law PV^n = a constant. Additional scales give directly in a single reading the work done in foot-pounds in an air compressor or by the Rankine cycle in a steam engine. The second group of curves gives the relations between temperature and volume of any gas according to the law TV^{n-1} = a constant; also this group of curves gives directly the work done in b.t.u. per pound. The third group contains curves for obtaining the cube or cube root and the 3/2 or 5/2 power or root of any number. The Conversion Chart represents more than 40 complete conversion tables, among the more important of which are:—Power conversions, speed conversions, linear conversions and volumetric conversions. Conversions between any units of the same order can be obtained directly without computation. Both these charts are printed on excellent grade of heavy bond paper and the curves are plotted on logarithmetic co-ordinates. The constants for all relations are included directly in the charts, and all values can be read with an accuracy about equal to that of a ten-inch slide rule. For any engineer who frequently has to determine values of steam or gas expansion or compression, or who has frequent occasion to change units of measure from one system to another, as for instance, from the metric to the English system, these charts will prove of great time-saving value. C. R. R.

"Experiences in Efficiency"—Benj. A. Franklin. 167 pages. Published by *The Engineering Magazine*. For sale by THE ELECTRIC JOURNAL. Price $1.50.

Mr. Franklin's book is presented in answer to many inquiries for successful examples of efficiency methods and operation. The material is selected from various wide and successful experiences and represents a diversity of situations in a variety of industries. Most of the chapters appeared originally in *The Engineering Magazine* and are reprinted in revised form. Four chapters are given to methods of increasing production; the fifth extends the same principles to nonproductive labor; the sixth enlarges the same ideas to include the entire force. Succeeding chapters discuss the broader phases of the problem, including the efficiency cost systems, etc.

NEW BOOKS

"Telephone Appraisal Practice"—J. C. Slippy. 6x9 inches, 97 pages. Published by the author. For sale by THE ELECTRIC JOURNAL. Price $4.00.

As the work of regulation of rates and service of utility companies by Public Service Commissions is extended more companies are required to prepare appraisals and valuations. There is still a great deal of information that may be made available to the profit of the majority of operating companies, so that each fresh publication on the subject adds to the store of data which may be consulted and utilized in order to place the final valuation report upon the most solid basis. Of course, the application of the different elements of valuation is possible of a wide range in treatment owing to the diverse views still held by reputed authorities and appraisal experts, and with this book we have another contribution to appraisal literature. While this volume is comparatively brief, it is confined, as the title implies, to the telephone branch of the art. It also applies to specific experience, giving inventory forms and unit costs, with a general introductory chapter on regulation, and closing with two chapters, one applying to depreciations and the other to commission requirements. In the matter of unit costs the author limits himself to a given locality and does not discuss the range in costs obtaining throughout the United States. However, he points out that the figures given are to be used for checking purposes. E. D. D.

"Test Methods for Steam Power Plants"—Edward H. Tenney. 208 pages, 85 illustrations, 33 tables. Published by D. Van Nostrand Company, New York City. Price $2.50.

Scientific publications on power plant topics have been quite abundant, but with the advance made in both science and actual practice preceding works may be enlarged and improved upon. Moreover, the subjects may be rearranged and handled in such a way as to facilitate the use of the information by operating men. In this respect the author succeeded admirably in producing a compact reference volume which will be of almost daily service to the power plant engineer in his effort to get the highest operating efficiencies. The author's knowledge acquired both theoretically and practically has afforded him exceptional qualifications for undertaking a work of this kind, which is reflected by the character of the book, which is intensely practical, with sufficient fundamental principles interspersed to provide an intelligent understanding of the work to be done. The book covers such problems as purchasing and testing of coal, efficient burning, analysis and treatment of feed water, testing of prime movers and the determination of the qualities of lubricants. As the conducting of tests of some nature is nearly a continuous performance in modern power plants, this handy manual will undoubtedly be accorded a prominent place in the library of the operating engineer. E. D. D.

"Purchasing"—C. S. Rindsfoos. 162 pages, illustrated. Published by the McGraw-Hill Book Company. Price $2.00.

Keen competition requires that manufacturers and users obtain their equipment and new materials at the lowest possible price. Consequently, the purchasing end of the business demands as careful consideration as that of production or operation. Unless the purchasing is done on favorable terms a handicap is established. As the selling of the commodity or output is the very life of any business, this function has been developed to a high degree. In general this would tend to place the buyer at a disadvantage when dealing with a highly trained salesman. The object of this book is to afford those fitting themselves for the work to counteract the strategy of the salesmen and to so conduct themselves as to secure the lowest prices. Certain attitudes and practices of some purchasing agents and buyers which they adopt to best the seller are shown to operate against him. The proper procedure in negotiating for low prices, etc., are set out in this interesting book, together with discussions on the necessary qualifications of the buyer, strategy, features of law, general purchasing organizations and references to forms that should be used. E. D. D.

"Human Nature and the Railroads"—Ivy L. Lee. 129 pages. Published by E. S. Nash & Co. For sale by THE ELECTRIC JOURNAL. Price $1.00.

The identification of the interests of the people with that of railroads is brought out in a clear and convincing way by Mr. Lee. It is shown that demands cannot be made upon the railroads without being based on some economic consideration, and that opportunity must be given to the railroad to meet its various obligations properly. In brief, one of the important features covered by the author is the fallacy of the attempt (by legislation) to increase the expense of the railroads without taking into account the revenues. This useful book comprises a series of addresses which the author gave before different civic, commercial and professional bodies throughout the country when he was executive assistant of the Pennsylvania Railroad. While the problems of the railroads are primarily considered, the discussions regarding the attitude of the public, the value of publicity, different phases of management, government ownership, etc., apply with equal force to all public utilities. Mr. Lee's manner of setting forth the serious and important phases of the present utility situation cannot fail to secure the immediate interest of the readers. E. D. D.

"Single-Phase Electric Railways"—Edwin Austin. 303 pages, 246 illustrations. Published by D. Van Nostrand, New York City. Price $5.00.

This is a large illustrated book based on material appearing originally in the columns of the (London) *Engineer* and refers mostly to European practice, including descriptions of the London-Brighton & South Coast Railway and the Midland in England, the Midi Railway in France, the Blankenese-Hamburg-Ohlsdorf Railway, the Dessau-Bitterfield Railway, the Murnau-Oberammergau Railway in Germany and Austria, the Mittenwald in the Tyrol, the Alpine railway known as the St. Polten-Mariasdell Railway, the Swiss line known as the Martigny-Orsieres Railway; also the Valle-Mattia Railway and the Rhaetian Railway, along with a section on the Lotschberg-Simplon Railway. The following chapter is devoted to the Rotterdam-Scheveningen Railway. In chapter VII is described the Thanholn-Loken Railway in Norway and the Rjukan Railway in South Norway. The Swedish State Railways are described in chapter IX. The concluding chapters are devoted to discussions of the New Haven, Spokane & Inland, the Rock Island & Southern, the Hoosac Tunnel and the St. Clair Tunnel electric lines in the United States. The entire work is illustrated with photographs and diagrams, and should be of considerable value as a book of reference regarding the present status of single-phase railway electrifications.

"How to Make a Transformer for Low Pressures"—F. E. Austin. 14 pages, illustrated. Price 25c.

This little pamphlet has been prepared by Professor Austin, of Dartmouth College, Hanover, N. H., and it explains a method of constructing, without expensive tools or machinery, a transformer to reduce the potential from 110 to about 8 volts.

THE CURB MARKET

FOR SALE

Generators

On account of changing our distribution system from single to three phase, we have for immediate delivery and in first-class condition one 180 K.W., 600 r.p.m., and one 120 K.W., 900 r.p.m., alternators; both G. E., Type A.S., 2300 volts, single phase, 60 cycle, belted machines, and complete with paper pulleys and exciters. Will sell very low if taken at once. Home Electric Heating Company, Eveleth, Minn.

Power Plant for Sale

250 hp. tandem compound Skinner engine, 200 r.p.m., direct connected to 200 kva Crocker-Wheeler generator, 240 volt' 3 phase, 60 cycle, complete with exciter and two panel board. This set has seen very little use. Also two 200 hp. Sterling boilers with 100 ft. stack and in A1 condition. Also Wheeler condenser pump, boiler feed pumps, air compressors, blowers, motors, etc. Will be sold very cheap. Address A. J. Stahl, South Bend, Ind.

Engine Generator Boiler

One 28" x 56" x 48" cross compound Rice & Sargent engine, direct connected to Westinghouse 1200 K.W., 3 phase, 60 cycle, 2300 v., 90 R.P.M. generator, including Blake Jet Condenser, bronze body. Also twelve Babcock & Wilcox water tube boilers, hp. rating 300; 180 lbs. pressure; including piping, suspensions, Roney Stokers and stoker drive. Boilers may be purchased with or without stokers. All apparatus in excellent condition, ready for immediate delivery. Address Narragansett Electric Lighting Co., Providence, R. I.

Light Plant for Sale

Instruments, switchboard, exciter, belts, 60 kw. generator, 100 hp. engine, 125 hp. boiler, heater pump, piping, etc., the complete 60 cycle, 1100 volt electric light plant recently shut down by the Waterford Electric Light Company, Waterford, Pa., on account of purchasing power.

1 General Electric Alternator, direct connected to a 16¼-28¼-30 Cross Compound Buckeye Automatic Engine.
Alternator Type ATB—No. 70919-150 R.P.M.—75.5 Amperes, 3 Phase, 60 Cycle, 2300 volts.

RATES

Positions Vacant, Positions Wanted, Agents and Salesmen Wanted—3 cents a word—minimum, $1.50 an insertion—payable in advance.

For Sale, Wanted and all undisplayed miscellaneous ads—3 cents a word—minimum, $1.50 an insertion. Proposals—$2.00 an inch.

Advertisements in display type costs as follows for single insertions:

1–16 page,	$ 4.00	1 in. single col.,	$ 3.00
1– 8 page,	8.00	4 in. single col.,	10.00
1– 4 page,	16.00	8 in. single col.,	20.00

Contract rates on application

FOR SALE

Steel Building

100 ft. by 260 ft. Crane Run Way, 22 ft. high.

IMMEDIATE SHIPMENT OR

will sell Building and Power Plant, with Lease of Ground. Two and One-half Years.Low Rental.

EDGAR M. MOORE & CO.,
Pittsburgh, Penna.

Dealers in First-Class Used Electrical, Steam and Gas Machinery.

EMPLOYMENT

Salesman

Eastern headquarters, with established trade wishes a line either exclusively or in conjunction with other goods, for the south, southwest and east

WANTED

Engine and Generator

High speed direct connected engine and A.C. generator, 2300 volt, 60 cycle, 3 phase, 400 or 500 kw. Also belted set as above. Address Box 508, Hazard, Kentucky.

Technical educated young men for work in our Testing Departments. Good opportunities for experience are to be had. Apply by letter, Employment, Box 011, Pittsburgh, Pa.

ELECTRICAL EQUIPMENT

IN STOCK FOR IMMEDIATE DELIVERY

STEAM TURBINE

One—500 K.V.A., 220 volts, 2 phase, 60 cycle, Westinghouse Alternator, direct connected to a Westinghouse Parsons Steam turbine, 3600 R.P.M.

DIRECT CONNECTED ALTERNATING-CURRENT UNIT.

One—105 K.W. Westinghouse, 220 volt, 3 phase, 60 cycle, alternating current Generator, direct connected to 15"x16" Buckeye horizontal side crank piston valve automatic engine, 257 R.P.M. This generator can be reconnected to 440 or 2200 volt.

DIRECT-CONNECTED DIRECT-CURRENT UNIT.

One—150 K.W. 250 volt, direct current Crocker-Wheeler, 8 pole Generator, type "CCD," direct connected to 14½"-24"x16" Wright horizontal center crank tandem compound automatic engine, 200 R.P.M.

Also several smaller sizes 110 and 220 volt in stock for immediate shipment.

ALTERNATING-CURRENT MOTORS.

One—50 H. P. General Electric, 2 phase, 60 cycle 220 volt, 900 R.P.M.
One—50 H. P. Westinghouse, Type "CCL," 2 phase, 60 cycle, 220 volt, 840 R.P.M.
One—50 H. P. Allis-Chalmers, 3 phase, 60 cycle, 220 volt, 840 R.P.M.
One—50 H. P. Burke Electric, 3 phase, 60 cycle, 220 volt, 900 R.P.M.

Also several hundred smaller size motors one, two and three phase, 60 and 25 cycle, 110, 220 and 550 volt.

DIRECT-CURRENT MOTORS.

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NEW BOOKS

"Engineering Economics"—J. C. L. Fish. 209 pages. Published by McGraw-Hill Book Company, New York City. Price $2.00.

A great many engineering problems in the industries are decided without proper and complete consideration being given the factors, both of first cost and operating expense. Equipment and structures are often selected that are economically unwise. Prof. Fish has brought together in his treatise several important principles that should be considered in connection with all engineering work. There are six chapters and useful appendices. The introductory chapter presents the underlying reasons for careful economic analysis. Interest, being the fundamental cause for an undertaking by capital, is discussed fully in the next chapter. Chapter III dwells upon the occasion and necessity for sinking funds so that the capital devoted to the undertaking is restored at the end of the life of the undertaking. First cost is the subject covered in chapter IV, and a careful study will disclose where glaring omissions are made. There is certain recoverable value when an undertaking involving physical property is discarded or abandoned, so that proper attention must be given to the salvage value as discussed by the author in chapter V. After fixed charges are determined, running expenses must be considered, so that the elements of the yearly cost of service is obtained as presented in chapter VI. In the next chapter methods of estimating and probable errors are considered. The final step to determine the most profitable investment in the long run is outlined in chapters VIII and IX, and followed by examples in chapter X. Those charged with the responsibility of recommending or passing upon expenditures of money may review this book with profit. E. D. D.

"Webster's Secondary School Dictionary"—Abridged from "Webster's New International Dictionary." 864 pages, 6¼x8½ inches; 1000 illustrations, 70 000 words and phrases. Published by the American Book Company, New York City. For sale by THE ELECTRIC JOURNAL. Price $1.50.

An exceptionally comprehensive abridged dictionary at a popular price—for the advanced student, for the office and for all kinds of general home reading, it fills every requirement that can reasonably be expected. It does not of course, include words of an advanced technical nature. It does, however, cover in a clear and definite manner all words, even of a scientific nature, liable to be met in general reading, distinguishing between those which are archaic or slangy and those which represent good usage. The definitions are especially valuable on account of the large number of synonyms, the specific meanings of which are differentiated, and because of the presentation, in most cases, of the original root from which the word is derived. At the same time definition by synonyms alone has been carefully avoided. The introduction includes an excellent guide to pronunciation and spelling; and dictionaries of proper names, of foreign words and phrases of frequent occurrence and of common abbreviations are appended. We unhesitatingly recommend this dictionary to any one who in the course of general reading or writing has occasion to determine the exact meaning of a word, or its spelling, yet who does not care to pay the price for, nor give up room on his shelves to an unabridged dictionary. Not the least of its merits are the excellent typography, good paper and high-grade binding so rare in an inexpensive dictionary. C. R. R.

"Principles of Depreciation"—Earl A. Saliers. 6x9 inches, 188 pages. Published by the Ronald Press Company. For sale by THE ELECTRIC JOURNAL. Price $2.00.

The subject of depreciation deserves more consideration than ordinarily accorded to it. Depreciation of the physical property is often taken care of in a superficial way and sometimes neglected altogether. Since the financial conditions of utility companies are being submitted to more critical inspection, depreciation should be treated in an adequate manner in order that the true status of the property may be known. Government regulation, both federal and state, makes provision for depreciation obligatory. The author shows how some of the courts and commissions have viewed depreciation. Chapters are given over to the consideration of the different methods of providing for depreciation and how the books of a company should be arranged to maintain the proper depreciation accounts. Problems and typical examples are worked out in detail; also many points involved are exemplified by diagrams. Engineers and accountants are being brought closer together in the scientific management of our utilities, and both can study this book to advantage. E. D. D.

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Industrial Motor Problems

Electric drive for industrial plants has so many unquestionable advantages with regard to economy of space, attendance, maintenance, etc., that hardly any but electric motors are now being installed where electric power is available. At the present time, the number of induction motors employed exceeds by far that of any other type, even when compared with the older direct-current shunt motors, because alternating-current power has been employed almost exclusively in the more recent installations on account of the greater ease with which alternating voltages can be transformed to suit the transmission or application of power.

But even without considering the advantages of the alternating-current system, it is usually advantageous to employ alternating-current power for the mere purpose of securing the inherent advantages of the induction motor, especially of the squirrel-cage type. The principal of these advantages is that no brushes or commutator, in fact, no sliding contacts of any kind are required, so that the bearings of the motor are practically the only part requiring any inspection and maintenance. In spite of this popularity of the induction motor, its working principles are not as well understood by operating men as those of the direct-current motor.

The article by Mr. A. M. Dudley on "Reconnecting Induction Motors," appearing in this issue of the JOURNAL, which deals in detail with some of the problems encountered by operating and consulting engineers, should, therefore, be welcomed. In fact, the article is so full of practical information that those who are not familiar with the theory of the induction motor will probably find it impossible to absorb all the information given at one time. Many, however, will find the article exceedingly valuable as a permanent reference for use when considering changes in the power supply conditions for induction motors. Material of this nature, based on many years of experience, also gives to the young engineer a valuable insight into practical operating problems. While it is true that to completely predetermine the performance of an induction motor under changed operating conditions requires a considerable degree of engineering knowledge, it is believed that by a careful application of the principles laid down by Mr. Dudley the average repairman can reconnect a motor so that its performance either will not be materially modified, or will be changed only to an extent which may be predetermined with reasonable accuracy, which is all that is ordinarily required.

R. E. HELLMUND

The Electrification of Railroad Terminals

One of the unfortunate results of the conditions under which the growth of our large cities has taken place is the congestion which occurs in practically all cases near the heart of the business district. The traffic problem, where widening of the streets is impossible, has been met by separating the faster from the slower traffic and superimposing one group over another by means of subways and elevated structures.

The congestion of railroads has not as yet reached the same degree as that of the city streets, but in some cases, notably at certain tunnels and terminals, has required careful consideration. Where the widening of the right of way has been impracticable, the problem has been met by speeding up the traffic by electrification of the congested section. In this respect the much larger amounts of power which can be concentrated in one train, and the superior accelerating ability of the electric car or locomotive as compared with the steam locomotive, have been prime factors in getting more cars over a given section of track in a unit of time. The reduction of train movements by the entire elimination of locomotives in suburban service has been a big additional factor in the reduction of congestion.

A notable example of the use of electricity for reducing the congestion of traffic over a portion of track, where the expense of any other method would have been almost prohibitive, is afforded by the Philadelphia-Paoli electrification of the Pennsylvania Railroad, described by Mr. George Gibbs in this issue of the JOURNAL. It is expected that this partial electrification will afford relief from congestion for six years, and that still further relief may be secured by the electrification of other suburban lines using the same station.

Mr. Gibbs' article is of especial interest, not only on account of his complete description of this great electrification and the results achieved thereby, but also by reason of the description which he gives of the methods of carrying out the actual construction work. The rapidity of the installation of the overhead construction, indicated by the figures given by Mr. Gibbs, may be considered as due in part to the very thorough design of all parts of the work on the drafting board, and also to the assembling of as much of the catenary construction as possible away from the tracks, so that the minimum amount of time was used in actual work over the tracks — a very necessary consideration on a system as busy as that of the Pennsylvania near Philadelphia.

CHAS. R. RIKER

The Philadelphia-Paoli Electrification

OF THE PENNSYLVANIA RAILROAD COMPANY*

George Gibbs
Consulting Engineer

THIS article was prepared to outline to engineers who have not specialized on railroad electrification those features of the Philadelphia-Paoli electrification which are of general interest; and for this reason it deals primarily with the physical conditions surrounding the installation, its general purpose and the kinds and character of traffic, and is not intended to be a comprehensive technical description of the entire electrification nor of its features in detail. The December, 1915, issue of the JOURNAL contained an engineering description of other features of this electrification.—(ED.)

THE decision of the Pennsylvania Railroad Company to electrify its Philadelphia suburban lines was intimately connected with traffic conditions at Broad Street Station. This station, when completed in December, 1881, contained eight tracks and handled 160 trains each day, with 18 trains in the rush hour. By the year 1889 the movement had grown to 421 trains daily, with 38 during the rush hour, and congestion already demanded an enlargement. This was effected in the following year by additions to the yard and by adding four station tracks. In 1894 four more tracks were provided, making a total of 16 station tracks and, although in that year the street railways were electrified and suburban trolley service inaugurated, thus reducing the pressure of short-distance suburban travel, the total train service continued to increase until 574 trains were handled daily in 1910, with 53 in the rush hour. Notwithstanding the completion of the Mantua tunnel for western trains and the routing of certain through trains via West Philadelphia, it was found that the station, and especially its approach tracks, were in 1910 forced beyond their capacity, thus causing frequent delays in bad weather.

The conditions of recurring congestion were in 1911 made the subject of an elaborate study. It will be realized that a comprehensive physical enlargement of a railroad terminal in the heart of a great city is a matter of extreme difficulty, aside from the question of expense, and involving, as it does, the acquisition of adjoining property and the regrading or closing of streets, it cannot be accomplished without great difficulty. Aside from physical enlargement which might be adopted as a final solution of the problem, consideration was given to the possible means for a more immediate relief, in order not to delay unduly the advantage to the public of adequate and punctual service.

It was found that electrification of certain services had sufficient merit to warrant its adoption, and the work was accordingly undertaken, starting with the service which promised to produce the greatest relief. This is the suburban service to Paoli, to be followed by the Chestnut Hill service and perhaps others later, as results may warrant.

Broad Street Station is of the stub-end type, and requires for each through train entering a minimum of four movements of train and motive power; when the train is split up the number of required movements often reach fifteen, and the average per train is eight through the interlocking at the yard throat. This point is the crucial one in the operation of the terminal, as it controls the junction between the sixteen station tracks and the eight elevated approach tracks. Congestion at this throat is due to the regular scheduled train movements in and out of the station, the shifting of cars and light drafts, and the movement of empty power. By electrification a number of movements are eliminated if self-propelled motor cars are substituted for cars hauled by locomotives. For instance, in such cases it is not necessary to provide for light engine movements to couple to the outbound train, or for the road engine which has brought a train into the station to follow it out on the return movement. Furthermore, there is some gain due to the quicker acceleration of the electric trains and by the shorter length of track occupied when the locomotive is omitted.

It is obvious that a reduction in movements can occur only in a motor car suburban service; in through service the substitution of an electric for a steam locomotive will result in no reduction of train movements. Therefore, for the purpose in mind, electrification of the suburban service only was considered.

There are five suburban routes out of the station, requiring 250 trains per day out of a total of 574. In the busy hour more than one-half of the total number of trains arriving and departing are suburban. The heaviest services are the Paoli and Chestnut Hill; and the estimated relief obtained by electrification of these two services is about 20 percent in the morning and 24 percent in the evening rush hours. In the station proper the relief is equivalent to the addition of one and one-half tracks, a factor which is, however, not vitally important, because congestion in the station is not as great as at the throat. This relief, it is estimated, based on the expected increase in travel, will suffice for a period of about six years. Electrification of the other suburban lines will extend this period materially and will enable plans for physical enlargement to be perfected and carried out.

Electrification will, it is expected, have other advantageous results, such as stimulating and increasing traffic and earnings because of the added attractiveness of the service; also in securing greater punctuality in this very difficult schedule, due to the possibility of applying ample power at the train.

*Revised by the author from a paper read before a joint meeting of the Philadelphia Branch of the American Society of Civil Engineers and the Engineers' Club of Philadelphia, Jan. 3, 1916.

Figures indicate some savings in operating costs from this electrification. These savings will, it is hoped, nearly carry the new charges. Thus, while the project does not appear to be an immediately profitable one from the standpoint of direct return, the increase in travel may make it so in the future, especially when all suburban lines are electrified. The work was undertaken mainly as an emergency measure, to relieve as soon as possible the uncomfortable conditions for the public at this great terminal. One favorable factor for the electrification should, however, not be lost sight of; physical enlargement of a station involves costs which produce no direct return, whereas electrification produces some operating savings which will, in part at least, carry the expenditure.

DESCRIPTION OF THE LINE

The present installation is from Broad Street Station to Paoli on the Philadelphia Division, 20.3 route miles. It includes the equipment of Broad Street Station tracks and the main yard tracks leading therefrom; also the car storage yard at West Philadelphia, the four main line passenger tracks to Paoli, and the storage yard at this latter point where the car house and inspection building are located. The total miles of track equipped are 93.6, of which the yards and sidings comprise 16.6.

FIG. 1—TYPICAL MAIN LINE CATENARY CONSTRUCTION ON A CURVE
Showing the cross catenary tubular bridge structure.

The line is ascending for practically the entire distance from Philadelphia to Paoli. The maximum gradient is 1.5 percent, averaging 0.7 percent for the first ten miles and 0.24 percent for the remainder of the distance. The line includes a large number of curves, about fifty percent of the entire line being on curves. The degree of curvature varies, with four degrees as a maximum.

Service—The electrified train service is wholly suburban; neither through passenger nor freight services are electric. To provide for these latter services would require electric locomotives and the establishment of outlying yards for the interchange of power and extensive engine terminals at these points. It would also introduce complicated problems in the way of rearrangement of engine runs, special freight switching and the incident delay to passenger services by the additional power interchange. It would not assist in the solution of the problem of congestion at Broad Street Station and was, therefore, not considered at the present time.

The electrified suburban service includes all of the Philadelphia-Paoli locals and expresses, consisting of 78 trains a day operated regularly on a half-hourly interval, with additional trains in the morning and evening rush hours. The half-hourly trains make all stops, while the extra rush-hour trains, five each way per day, omit stops between Fifty-second street and Ardmore both ways. There are nineteen intermediate stations on the line, making the average distance between stations about one mile. The running time under steam conditions was 50 minutes for eastbound local trains and 57 minutes for westbound local trains. Under electric operation it was desired to shorten this time as much as practicable, and the equipment was laid out to operate at 47 minutes eastbound and 50 minutes westbound. At present, as initial operation, the runs are made in 49 and 52 minutes, respectively. This is equivalent to an average speed, including stops, of practically 25 miles per hour. This speed may not at first sight be considered high, but it is an excellent performance, and under steam conditions could be made only with very powerful locomotives, and even then with no margin to spare. The maximum power taken during acceleration by an eight-car train during the electric run is about 6800 horse-power per train, or 850 horse-power per car. An examination of a large number of suburban schedules both in this country and abroad indicates that this service is one of the most exacting found anywhere.

In operating the present electric schedule the power supply at Arsenal Bridge for short time peaks is about 20 000 kilowatts, and the average hourly demand during the rush hour is about 6000 kilowatts. The average per day is only about 2000 kilowatts. The power demand for this class of service is thus not only considerable, but is very fluctuating in character.

TRAIN EQUIPMENT

To operate the required schedule with sufficient reserve, 93 cars have been provided. These are the stand-

ard passenger car of the 54 ft. body class (MP-54). It was found that in order to meet the schedule speeds two of the most powerful electric motors, which could be put in the available space underneath one truck of the car without raising the car floor or weakening the underframe, were required. Therefore, in order to make the schedule independent of the number of cars in the train, all cars were equipped with motors.

A number of years ago when the design of steel cars was first taken up by the road, the dimensions and construction were considered with the view of their possible conversion for electric service. In this way practically no changes were required in adapting the cars which had been used in steam service for the electric service, except the addition of platform-end doors to form a motorman's compartment and the substitution of a motor for a trailer truck. The equipment was modified for the required change in lighting and heating methods, and the brake rigging was changed to the latest form of electro-pneumatic brake with clasp brakes on the truck wheels. As the underframing had been laid out for the convenient installation of electric apparatus under the car, no changes in this essential part of the car body were necessary.

Electrical Equipment—The equipment of each car consists of two 225 horse-power forced ventilated motors mounted on one truck. These motors were specially designed for this service by the Westinghouse Company, and are known as the series repulsion type of alternating-current motor. They start as repulsion and operate as series motors after a speed of twelve to fifteen miles an hour is reached. The motors are geared to the axles in the usual manner except that the gears are flexible; that is, the torque of the motor is transmitted from the teeth of the gear to the axle through cushioning springs. This device smooths out and reduces the vibrations due to frequency alternations, and also materially reduces shock on the gears and pinions. The control equipment is of the Westinghouse electro-pneumatic type arranged for automatic acceleration of the motors. All minor appliances have been used according to the best modern practice in this equipment.

ELECTRIC SYSTEM

In order to determine the proper electric system for the Philadelphia installation a careful analysis was made of all those available, not only for the present work and its probable extensions in and around Philadelphia, but for the possible future application of electric traction to long distances on the main lines of the road. Because of the fact that the company had an important and successful third-rail, direct-current electric installation at its New York terminal, it was naturally predisposed to adopt the same system in Philadelphia, provided it was found suitable for long-distance extensions in the future for all kinds of traffic. It must be remembered that the character of the New York installation was [illegible] the local conditions in an underground terminal [illegible] the state of the art at the time [illegible] was decided upon, nearly ten years ago. Therefore, the presence of this system, while it should, of course, be considered, ought not to operate to handicap future extensions there and elsewhere, especially if a new and better system had been since developed and could be made to operate harmoniously with the existing system.

It was concluded that an overhead contact wire conveying high-tension alternating current was the most suitable system for long distance traction with heavy and relatively infrequent train units. This type of "working conductor" was also regarded as presenting the fewest objectionable features for the equipment of large and complicated yards. The system as a whole is known as the "single-phase;" it has been made familiar

FIG. 2—TYPICAL CATENARY CONSTRUCTION ON THE MAIN LINE TANGENT TRACK

by the important pioneer example on the New York, New Haven & Hartford Railroad between New York and New Haven. In this installation the locomotives of the New Haven Company must operate also in the direct-current, third-rail zone of the New York Central Railroad. This is accomplished by equipping them with two kinds of contact and control devices, but the motors operate on either system without change. This peculiar feature of an alternating-current motor provides for interchangeability of an alternating-current locomotive or car on either system of current supply, but where direct-current locomotives are employed the case is not so simple. The locomotives cannot be run on an alternating-current line by merely equipping them with

double contact and control; they must be also provided with some means which will change the alternating current into direct current. An extremely simple and efficient appliance for the purpose, the mercury rectifier, has, fortunately, been lately developed, and it is now possible to operate direct or alternating-current motors interchangeably on either an alternating or a direct-current line. The development, therefore, of a rectifying means for the conversion of alternating into direct current was the last step needed to unify the operation of the two prominent existing electric systems, and enabled the company to adopt the most modern system in Philadelphia with the assurance that if in the future Philadelphia and New York are electrically connected the two systems will work together to make a complete operating division.

Characteristics of the Single-Phase System for the Philadelphia Electrification—The single-phase system, in its essentials, comprises:—a power supply of high-tension, single-phase alternating current; its transmission along the railway over a two-wire circuit to sub-stations, where it is passed through a transformer to produce the desired trolley voltage (generally lower than the transmitting voltage); a trolley wire over the track; and a track return circuit to the sub-stations. Current for the car or locomotive is taken from the trolley wire by a sliding device, and by means of transformers is changed to low potential for use in the motors. These essential elements are incorporated in the following manner in the Philadelphia-Paoli electrification:—

Power House—A separate power house was not built for the Philadelphia installation. Single-phase, 25 cycle, alternating-current power is purchased at 13 200 volts from the Philadelphia Electric Company and delivered through submarine cables from their Christian Street station to the Arsenal Bridge sub-station erected by the railroad company across the Schuylkill river. At this point it is metered and passed through transformers which step up the voltage to 44 000 for transmission along the electrified tracks.

The Philadelphia Electric Company conducts an extensive commercial business in both lighting and power, and for these purposes generates both 60 and 25 cycle, three-phase current. In order to furnish properly regulated 25 cycle, single-phase current, under the conditions of widely fluctuating load required for the Paoli line, from their three-phase generators, the electric company found it advisable and economical to provide special phase balancing apparatus in their power house, and synchronous condensers on the railroad company's line. This gives them balanced power of approximately unity power-factor at the switchboard and improves their generating conditions for a varied commercial business.

Transmission Line—Four 44 000 volt transmission lines of two wires each leave the Arsenal Bridge sub-station and are carried north along the elevated freight line to a main distributing sub-station located near the track at West Philadelphia. From this point two circuits continue on the catenary supporting structures, one circuit on each side of the tracks, to Paoli; the remaining two high-tension lines will serve the Chestnut Hill Branch electrification, now under construction. The transmission lines are of No. 00, seven-wire, hard-drawn copper; they are spaced five feet apart horizontally and, where there is more than one circuit on a pole, the vertical spacing is three feet six inches. In order to keep the voltage to ground as low as possible, the middle points of the 44 000 volt windings in the step-up transformers in the Arsenal Bridge sub-station are connected to ground; this reduces the potential to 22 000 volts between any transmission wire and ground.

Sub-stations—Three working sub-stations are provided for the system. The Arsenal Bridge sub-station is used for stepping up only at present, but it may be used also for a working sub-station if electrification is later extended south on the Wilmington division. At West Philadelphia is the main working sub-station, and controls the distribution of power throughout the system. In it is stationed the power director, who is the only regular sub-station attendant provided on the line. The second sub-station is at Bryn Mawr, 10.2 miles from Arsenal Bridge; and the third is at Paoli, 20.1 miles from Arsenal Bridge. All sub-stations adjoin the tracks, so that the transmission wires and outgoing trolley feeders may be conveniently reached.

The buildings are of brick and fireproof throughout. They contain static transformers on the ground floor, bus-bars and switching equipment on the second floor and lighting arresters on the roofs. The transformers are installed in duplicate and are of the oil-insulated, water-cooled type. At Arsenal Bridge there are three 5000 k.v.a. step-up transformers to supply power to the transmission lines; the three working sub-stations have each two 2000 k.v.a. transformers for the trolley feed.

The high-tension current in the sub-stations is switched by means of circuit breakers, which are automatically operated and also electrically controlled from the nearest signal tower, as well as from the sub-station switchboard. Indicating lamps and alarms are provided, so that the tower operator is aware at all times of the conditions in the sub-stations.

Catenary System—The catenary structures which support the trolley wires over the tracks contain perhaps the most novel features in the present electrification. It may, therefore, be interesting to trace briefly the development of this essential part of the electric system.

The first use of a trolley was for electric street cars. It consisted of a copper wire erected longitudinally over the center line of the track and held by clips from insulators which, in turn, were attached to cross wires carried by wooden poles at the sides of the track. The trolley wire was lightly stressed and hung more or less in festoons, being quite loose in hot weather and more level in cold. It served its purpose well enough as contact for a deeply flanged trolley wheel running under it at low speeds. When the arrangement was adopted for heavy and high-speed service on steam railroads, im-

provements and further safeguards in the type of construction were essential. It became necessary, in order to insure continuous electrical contact, to maintain the wire in a practically perfect plane parallel to the track; it was inadmissible to have sudden variations in tension or height, as these would cause the collector to jump from the wire or to so vary in pressure as to give imperfect contact at speed. It was also necessary to substitute a pan or bow type of collector for the trolley wheel, to prevent the possibility of the collector leaving the wire and thus causing a wreck either of the device or the wire and supports. The first important improvement in construction was to provide an auxiliary longitudinal support for the contact wire. This took the form of a cable, which was erected with a considerable amount of sag between supporting bridges. It assumed approximately a true catenary curve when loaded at equidistant points by the trolley wire held in a plane below it by hangers of varying lengths; thus the arrangement has come to be known as a "catenary system." While this provided a greatly improved contact surface, it introduced a hard spot, due to the inflexibility of the hangers at each point of support. At low running speeds this defect was not important, but at

FIG. 3—STANDARD MUTIPLE-UNIT TRAINS LEAVING A STATION

high speeds it was apt to cause the pantagraph to lose contact momentarily and to produce injurious sparking. A more flexible catenary system was, therefore, devised by providing an auxiliary messenger wire supported from the main messenger by hangers; below this the main trolley wire is suspended by clips at points intermediate between the main hangers. This gives approximately uniform flexibility and sparkless collection of current at any running speed.

In the early examples of catenary construction, notably on the first section of the New Haven road electrically operated, it was thought necessary to provide lateral stiffness for the system by the use of two messenger cables instead of one, which, through the rigid hangers, gave a triangular support to the contact wire. This construction, however, has been found unnecessary and even objectionable in being too rigid on curves. All the latest systems use a single messenger cable.

The catenary wire system is carried at suitable intervals by some form of bridging across the tracks. These supports, in early examples, were made very rigid and cumbersome, employing latticed steel posts and cross trusses. While this construction is good, it is expensive and somewhat unsightly; it also obstructs clear view along the track. A lighter and more sightly construction has been found admissible and advantageous, and designs with these objects in view were accordingly made for the Philadelphia electrification. Before finally deciding upon the best type, however, an experimental four-track catenary section about a mile long was erected, embodying various types of structures, as well as of the details of hangers, insulators, etc. An examination of this work by a committee of the operating officials of the road resulted in the selection of what is called a "cross catenary tubular bridge" to carry the longitudinal catenary. This form of construction provides a simple and relatively cheap structure which interferes with the view along the track as little as possible and which, furthermore, presents least surface, and that of the simplest kind, for repainting.

Catenary Design—The design of a catenary structure, especially for a multiple track railroad having a large number of curves of varying radii, is a complex operation. Not only the static loads including ice loading, but wind pressures, temperature movements and effects of curve pull-offs, must be provided for with proper factors of safety. Static loading, including loads due to wind pressure on ice-covered wires, etc., are readily computed; the temperature movements on tangent construction may also be readily computed, but the effects of temperature in the curved portions of the line are, owing to the elasticity of both messenger and trolley, difficult of computation. An elaborate series of experiments was made on the trial line to measure temperature effects under these varied conditions and formulae were deduced to apply. Observations made recently on typical wires of the completed work show movements in substantial agreement with these computations.

The assumptions used for loading provide for one-half inch coating of ice on all wires and a wind pressure of eight pounds per square foot on the projected surface of the ice-covered wires. Unit stresses in any part of the structure, under these conditions, include suitable factors of safety within the elastic limits.

The contact trolley wire is No. 000 copper specially treated, with the addition of a slight amount of alloying metal to produce a dense, uniform product. This wire is suspended by clips at intervals of 15 feet directly from a secondary copper messenger of No. 0 size, and this secondary is in turn hung from a seven-strand galvanized steel messenger cable about one-half inch in diameter at intervals of 30 feet and midway between the suspension points of the running contact wire. This cable has an ultimate strength of about 30 000 pounds.

On curves, where the system must be restrained to coincide with the center line of the track, both trolley wire and secondary are carried by the same hangers, spaced 15 feet apart. A smooth curve is produced by inclining the hangers from the vertical and offsetting the messenger at the points of support on bridges. This construction has the great advantage of eliminating pull-offs, which tend to produce hard spots or rigid points in the contact wire.

The trolley is designed to lie in a plane parallel to the track at a temperature of 60 degrees F., producing normal tension in the running wire of 3000 pounds and 3500 pounds in the steel messenger; the secondary is stressed about 1000 pounds only. To produce these stresses the vertical sag of the messenger is about five feet in the center of a 300 foot span. The spans are generally 320 feet on tangents and closer on curves as limited by the amount of space available in which to offset the messengers on the bridges.

The normal height of trolley wire is 22 feet above the top of track rail; in Broad Street station and yard it is 20 feet, and is still lower under certain overhead highway bridges and in tunnels.

The effect of temperature variation in a catenary structure is to alter the tensions and positions of the wires in relation to the track. In foreign installations, especially those on the continent of Europe, elaborate devices are often used to insure uniform tension in the contact line with varying temperature. The plan usually adopted is to divide the contact line in sections, say, one-half mile long, and to fix the wire at the middle of each section, stretching the two ends by automatic tightening devices, which produce tension by weights attached to chains running over pulleys. As the catenary is made up of wires of different materials (steel and copper) having different coefficients of expansion, complications are introduced in carrying out consistently any automatic tension scheme. Its proper operation is also predicated upon the free movement of all wires at the points of support, a condition which is difficult to secure in practice, and the presence of sectionalizing devices, overhead wire curves, or of switches and cross-overs in the trolley all add to the complication. The writer, who has conducted a number of experiments with automatic tension devices in order to test their applicability to American conditions, believes that, for the present at least, it is inadvisable to complicate overhead structures with such devices in advance of positive knowledge that they will be needed.

FIG. 4—CROSS CATENARY STRUCTURES OVER MULTIPLE TRACK SECTION

The result of not using automatic tension is that there is a maximum vertical movement of the trolley wire on tangents of about 12 inches for 100 degrees of temperature range, and in curves this movement may be as much as 30 inches, with 20 inches horizontal movement. It is believed to be better to stand the inconvenience of these movements and, possibly, the necessity for some seasonal adjustment of the system to prevent them from becoming undesirably great, rather than to add complicated correcting devices which, at least for the present, are not thought to be essential.

Insulators—To secure reliability of service, adequate insulation of an overhead trolley line is of vital importance. Unfortunately, electrical insulators must be of materials which have undesirable mechanical features; only porcelain or glass can be used, and these have practically no strength except in compression. The insulators must, therefore, be designed to be free from bending strains in service. This limits the design of insulators to certain forms and makes the applications at times awkward. In accordance with the policy adopted in carrying out this electric installation, it was endeavored to make the line insulation of the very best. To do this it was determined to provide on the portion of the line which is subject to considerable hard usage at least double insulation, each unit designed to be sufficient in itself. In parts of the line subjected to the most uncertainty or abuse, triple insulation to ground was provided. The transmission line is not subjected to such severe conditions, and there single insulation has been used.

The material of the insulators has been made the subject of very careful study. It was finally decided to adopt American porcelain insulators made by the wet process, special care being taken to produce mixtures which would withstand sudden changes in temperature and make a homogeneous product best fitted to resist electrical stresses. The problem of obtaining perfect insulators seems to reside chiefly in getting a proper mixture free from impurities, and in moulding it with-

out voids and firing it at the proper temperature. If the insulator is over-fired it will be very brittle, and if under-fired too porous, so that it will absorb moisture and fail electrically.

For the high-tension transmission lines, the insulators adopted are of the pin type of four-piece porcelain. The petticoats are 12 inches in diameter and the insulator proper is 8.5 inches high. The insulator has a dry flashover test of 165 000 volts, a wet flashover test of 120 000 volts, and a puncture test of 250 000 volts. After erection, all transmission lines were tested out to a potential of three times the working pressure to ground.

For catenary insulators a novel type of triple insulation was devised. The conditions to be met are many; the insulator must not only be sufficient electrically, but mechanically it must have a large factor of safety to prevent breakage due to the weight carried and temperature variation; and should be of a design that can be adapted to the simple attachment of the catenary and will give the greatest distance possible from the live wire to the ground. This latter requirement is not only necessary to prevent electrical flashovers, but to guard against accidental grounding across the insulator by birds or small quadrupeds which seem to have a fondness for using the catenary structure as a resting place. A study of all conditions led to the adoption of a suspension type catenary insulator, consisting of three porcelain discs in series, each disc being eight inches in diameter and cemented into a malleable iron cap. The porcelain and the metal part are put together at 120 degrees F., so that in cooling they will not produce bursting strains on the porcelain by differential contraction.

Each insulator is subjected to thorough tests, one for electrical flashover and puncture and another for mechanical strength. Electrical tests are made both wet and dry, and under the worst conditions must show in the completed unit a factor of safety of ten in the wet test and twenty in the dry. Mechanically the breaking strength of the suspension insulator is about 18 000 pounds; the maximum working load is 5500 pounds.

Catenary Supports—Cross-catenary, guyed, tubular pole structures were adopted for reasons of simplicity, cheapness and sightliness, and are used for all four and six track main line construction. For double or single track work and in special locations, such as at West Philadelphia, tubular and (in some cases) structural bracketed poles were used. In the extensive terminal yard at Broad street, cross-catenary construction is used with unguyed latticed steel side posts.

With the tubular form of construction it is impracticable to attempt to take care of the very heavy overturning moments at the foundations, as poles which are of workable size are incapable of standing large bending moments. Accordingly, the poles were made of the proper size to take the compressive stresses, and the lateral overturning is resisted by double back-guys. The foundations were, therefore, designed to take only a small overturning moment laterally; this moment is caused by the tension due to trolley pull-offs, which are applied some distance below the point of attachment of the guy, thus putting a slight bending moment in the pole. The poles were considered essentially as compression members fixed at the base, and the foundations are accordingly of moderate size, containing generally not more than four cubic yards of concrete. The poles vary in diameter from 8 to 13 inches inside at the butt, and terminate in a four-inch diameter piece above the point where the guy rods are attached, to carry the ground wire. The poles have a thickness of one-half inch, but at the point where they leave the foundation they are protected by a one-half inch thick band. They are swabbed on the inside with pitch and are fitted with screw caps and sealed air-tight.

Guy Rods—The guy rods are formed of two steel rods placed at an angle of 60 degrees with each other on the horizontal projection and intersecting at the center of the pole. It is not difficult to take any desired amount of tension in this form of construction, but its success lies in the sufficiency of the anchorage. The

FIG. 5—TYPICAL CATENARY CROSS-OVER IN YARDS

ground around Philadelphia is generally of firm clay, shale or disintegrated rock. All these were found to be of sufficient stiffness to make it possible to excavate foundation trenches with vertical walls and to thus keep down the excavation to a minimum for proper holding power of the anchors. Tests were made of various types of anchors. The type finally adopted as most reliable and economical consists of a rectangular concrete slab surrounding pieces of old rail or beams set in a longitudinal direction in the excavation and having guy stubs attached to the rails. These stubs project a short distance above the ground surface and are encased in old boiler pipes filled with grout; they form a permanent attachment for the guy rods, which were coupled to them later. The guy anchors were assumed to engage a prismoid of earth bounded by planes touching the upper edges of the slab and inclining outward at an angle of 30 degrees with the vertical. When in an embankment only that portion of material forming a symmetrical body was assumed to act in resisting uplifting. A factor of safety of 1.75 was used.

No case of guy yielding has yet been reported in the many hundred of foundations placed.

The upper portions of the guys consist of round rods with an eyebar head at the top and thread at the lower end, connecting to the stub with a turnbuckle. The size of the rods varies in accordance with the stresses from 1.25 to 2.5 inches in diameter, from which it will be seen that the tensions to be taken care of are great, amounting in some cases to 85 000 pounds per rod. The largest standard size of anchor slabs was 4 feet wide by 6.5 feet long and 18 inches deep.

This entire cross-catenary construction is designed to be rigid transversely with the tracks, but provides for considerable longitudinal flexibility, which is an advantage in distributing the stresses due to temperature changes to the anchor bridges, and prevents excessive unbalanced loads due to any breakage in the longitudinal wire system. At certain places along the line where property lines were close guys could not be provided, and in such cases latticed structural poles were used with foundations designed to resist the overturning moments.

Numerous composite wire dead-ending and signal bridges have been provided along the line; these are spaced primarily with reference to the requirements of the block signaling, and are on the average about 2700 feet apart. These composite bridges are quite massive, a typical four-track bridge weighing about 30 000 pounds, with about 60 cubic yards of concrete in its foundations.

In Broad Street Station yard the catenary structures must, in some cases, span 13 tracks, or about 115 feet in the clear between supports. The posts, which are of the self-supporting type, are in some cases 45 feet high, in order to provide the clearance for the trolley wire above the top of rail. They must be, therefore, very stiff, and of the latticed type and set on or supported by the masonry of the elevated tracks. The overturning moments are provided for by a structural steel toe projecting under the tracks and bearing on the masonry of the fill.

Sectionalizing—The working conductors of all electric systems are cut into separate sections in order to facilitate repairs and to localize troubles. This sectionalizing is accomplished in the overhead trolley system by making a short gap or break in the catenary and trolley wires. The messenger is sectionalized by insulators and the trolley wires by one of several different methods. The best means for high-speed running appears to be to overlap the two sections in a span, changing the elevation of the wires at the overlap so that the car pantagraph will run smoothly from one section to the other. Tension in the wires at the overlap is maintained by transference through porcelain insulators and no insulation is, therefore, required at the point of contact except that furnished by the surrounding air. These section breaks are introduced in yards, at all sub-stations and at anchor bridges where track transformers are installed to prevent inductive effects in telephone and telegraph wires.

In yards numerous section breaks must be employed to sectionalize the tracks in groups, and the ladders must be sectionalized at each track. This complication appears to be unavoidable, and as the train speeds are slow at such points a simpler type of section break, which requires less space to install, is used.

Lightning Protection—It is necessary to provide means for the protection of the system in case of lightning discharges. The transmission lines appear to be the vulnerable part of the system as a collector of air potentials. A ground wire installed above each transmission line furnishes a generally efficient protection. To provide, however, for the possibility of lightning discharges, which may reach the line in spite of this protection, injuring the apparatus in the sub-stations, special arresters of the "electrolytic" type are provided at the sub-stations. It has been found by experience that an ungrounded catenary system has given very little, if any, trouble from lightning; this immunity is

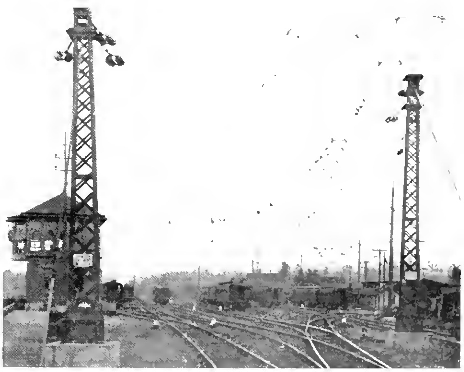

FIG. 6—LATTICED STEEL POLES AND CATENARY CONSTRUCTION IN YARDS

probably due to the great number of grounded steel structures which span the tracks and carry these wires.

CONSTRUCTION METHODS

As the electrification covers one of the busiest and most important main line sections of the Pennsylvania Railroad and includes the equipment of a large and congested terminal, the methods employed to insure prompt and safe conduct of the erection work will be of interest. All designing and all construction, except the purchase of electric apparatus and the erection of the sub-station buildings which were contracted for, was carried out by the regular departments and the special forces of the railroad company.

Designing—The first important operations were in the designing offices, where the plans for all structures were made in detail. The field forces were supplied with exact information for all foundations, which was the first field operation undertaken. It was especially important to avoid, as far as possible, all cutting and fitting of wires, hangers, etc., in the field; hence elab-

orate and complete plans were made in the designing room to determine the position which the trolley wire would assume at each and every point over the line with certain predetermined sags, the location of the messenger in reference to the tracks, etc. The calculations established the lengths of all trolley wire hangers, which were from these plans furnished to the field cut to length and fitted with their attachments. When put into position it was found that the trolley hung in its proper plane and position with but little field adjustment. While this process involved a large amount of designing, it is felt that it was amply justified by the resulting saving in cost and time during the construction period.

The main elements in the construction work were disposed of as follows:—

Foundations—Excavations for about 112 bridge foundations were required. The soil was for the most part of clay which was stiff enough to require no shoring when the excavation was followed closely by the concreting. Some rock, however, was encountered in portions of the line, and where found was cut out by air hammers, as the work was so close to the tracks that blasting was considered dangerous.

Concreting—The aggregates for foundation concrete were distributed by a work train in approximately the required quantities adjacent to each foundation. All concrete was hand-mixed on boards, in the proportion of 1—2.5—5, and was poured very wet, so that it was not necessary to do a great deal of tamping.

The tubular pole foundations, which were rectangular in cross-section and of varying dimensions, were provided with vertical rods and reinforcing hoops of one-half inch twisted rods for shear. These foundations required no foundation bolts, as the pole is set in a center hole formed by a collapsible core. In general, the foundations required no forms except just below and above the ground, as the clay was stiff enough to stand up properly until the concrete was poured. As far as practicable, the excavation for the ground end of the anchors was made at the same time as that for the pole foundations, and the concrete slab at the bottom of the anchor was poured at the same time as the main foundation.

Catenary Supports—The foundations were practically all completed before the erection of bridge structures began. The poles were unloaded near their respective locations, and while lying on the ground were fitted with attachments, such as cross-arms, castings, etc. The poles were then lifted into place in their foundations by using a derrick car. They were afterwards lined up and shimmed in place by wooden wedges, which held them until the work train followed and grouted them permanently in place. The anchor and signal bridges were erected into position by a derrick car from the freight car on which they were received.

Cross Spans—The next operation was to erect the cross-catenary between the side poles. This structure consisted of top and bottom wires with their connecting links all previously fitted together at the construction yard. These pieces were loaded on a work train and hung in place from the train. The whole catenary pole span was then completed by putting on its guy rods after making final adjustments for tensions, and was then ready for the erection of the longitudinal catenary.

Longitudinal Catenary—When enough structures and bridges were in place and the insulators suspended from them, wire stringing work trains were organized. These were usually made up of one or two flat cars to carry the reels of wire, one or two tower cars and a box car used as a material and tool car. The steel messenger wire was fed out from the top of the tower car and strung from anchor bridge to anchor bridge and adjusted to the proper unloaded tensions, which were furnished by the office. Until final adjustments were made this messenger wire was supported on pulley blocks suspended from the insulators, thus allowing it free play longitudinally. These blocks were removed later and regular supporting castings substituted.

The cable, while suspending its own weight only, was given such a tension as would be necessary to insure proper sag when fully loaded. This tension was computed and furnished the field by means of the curves showing the relation between temperature and tension for each stretch between anchor bridges. The proper tension was obtained by means of a dynamometer and the cable allowed to stand awhile and adjust itself to approximately uniform tension throughout its length and then finally socketed and anchored at both ends.

Following the erection of the messenger wire a train made up of several tower cars would mark the proper location of the hangers on the messenger in accordance with the drawings and fasten in position the hangers which had previously been cut to length and fitted with castings. The next operation was to string the auxiliary and the main trolley wires from anchor bridge to anchor bridge, holding the wires temporarily at the bottom of the hangers by means of iron straps which could readily and quickly be applied. The final operation was to adjust the trolleys to their proper tensions by a train of tower cars and to clip them in. Where cross-overs, section breaks, etc., occurred the fittings were put in as a last operation, as they required generally one or two tower cars only to accommodate the workmen who could be employed to advantage in the short lengths involved.

Work Trains—The composition and proper management of the work train service was very important, in order not to block regular traffic unnecessarily. Practically all work was done by daylight, night work being permitted only for a period of about two months in Broad Street Station in order to clean up certain work which could not be done by day on account of the traffic. The rapidity of the progress of the work was largely regulated by the amount of time the tracks could be given up for the occupancy of work trains. Generally, on the four-track portion of the main line the inside

track of the inbound pair was occupied in the mornings and the inside track of the outbound pair in the afternoons. The stringing of wires over the outside tracks was done from the middle tracks by outriggers on the tower cars, so designed that they could be occupied by the workmen without interfering with the steam traffic underneath on that track. In all ten flat cars were equipped with towers, the working platforms of which could be readily raised and lowered by means of chain blocks. When in the lowered position the towers have a height of 18 feet 6 inches above the rail, with a possible raise of 4 feet.

Men Employed—The men employed in the construction work varied in number from 200 to 685, and were variously divided into gangs at different stages of the work between laborers on excavation and concrete, iron workers on erection of structures, linemen for stringing the wires, bonding gangs on track bonding, carpenters on forms and miscellaneous workmen and wiremen on equipment of sub-stations.

FIG. 7—SIGNAL AND SECTIONALIZING BRIDGE
Showing beam light signals and booster transformers.

Amount of Work Done—Foundations for catenary bridges were completed at the average rate of about two per day, reaching six per day at the maximum. With the derrick car twenty-five poles could be picked up and set in place per day. The tubular bridges were erected and completed at the rate of two per day. The erection of longitudinal wiring, including messenger and trolleys, clipping in and adjusting, etc., was completed at the rate of 3.1 track miles per day for straight-away work. The wire train stringing four wires at once could run out eight miles a day. In complicated yard work the progress was, of course, much slower. Thus, at the various interlockings in the Broad Street terminal, a given section of tracks could not be occupied for any great length of time, so that much time was necessarily lost in waiting and switching in and out of position. In this location, moreover, the work was extremely complicated and tedious, as there were about 44 cross-overs and 50 switches in the portion of the yard electrified. There were generally three trains at work in this section and one train at night. It required the equivalent of one train at work for about twenty-six weeks to string the trolleys and clip them in and to make the section breaks, cross-overs, etc., complete. Track bonds were applied at the rate of about 250 bonds a day.

OTHER SPECIAL FEATURES

A number of novel accessory features were provided for the installation. Some of the more interesting accessories are:—

Inductive Protection—In order to reduce inductive interference of the traction currents with the operation of telephone and telegraph lines, series or booster transformers have been installed in the track circuit. These transformers are located on signal bridges approximately one mile apart. The primaries of the transformers are in series with the trolley wires, and the secondaries are connected across the middle points of impedance bonds at insulated joints in the track. As all of the trolley current supplied must flow through the primaries of the booster transformers between the substation and the load, all of this current must flow through the secondary of the transformer, and thus is kept in the back rails instead of returning through the earth.

Bonding—In order to make that part of the electric circuit represented by the track rails continuous and of low resistance, all joints are bonded with copper bonds. Two bonds are used on all joints and (except at interlockings) both rails carry traction current. At signal blocks impedance bonds are connected across the break. These impedance bonds are so designed that they permit the passage of 25 cycle traction current, but effectively sectionalize the 60 cycle signal circuit.

Signals—Power for the operation of the electric signals is supplied from motor-generator sets in the West Philadelphia sub-station under normal operating conditions, but in case of emergency may be supplied from a separate source at the Paoli inspection building. In the West Philadelphia sub-station there are two 150 k.v.a. motor-generator sets supplied with power from the 11 000 volt bus-bars through a transformer. This transformer steps the voltage down to 2200, at which potential it is supplied to the single-phase motors of the motor-generator sets. Power is generated at 3400 volts, 60 cycles, and supplied to the four signal feeders. There is also in the West Philadelphia sub-station a 150 k.v.a. transformer, which is supplied with power from the Philadelphia Electric Company, for emergency use. At Paoli a 75 k.v.a. motor-generator set is located in the inspection building power house, and power for its operation is supplied from the 11 000 volt bus in the Paoli sub-station through a step-down transformer.

The most interesting feature of the signaling of the electrified section is found in the novel type of signal used. The usual semaphore signals have been replaced by beam light signals of a type devised by Mr. Rudd, signal engineer of the company. This signal consists of a number of light units or lamp bodies assembled on a framework in various combinations. The pipe frames

on which the lamps are mounted are stationary. In the case of a three-position signal there are three arms—one vertical, one at 45 degrees and another at 90 degrees. A total of ten lamps are required to give the three positions. Two-position signals require only seven lamps. The inverted lenses are equipped with "no glare" cover glass, which has a yellowish tinge and renders the light more distinct. At the focus of the lens there is a 12 volt, 5 watt, concentrated filament tungsten lamp. A hood is provided to shield the lens from the direct rays of the sun. In order to present a better short range indication a glass mirror is mounted above the lamp in such a position as to cast a light downward towards the base of the signal. The transmission factor of these lenses is high, due to the absence of color.

Telephone and Telegraph Lines—On account of interruptions to telephone and telegraph service following heavy sleet storms, all wires and poles have been removed and cables installed in underground conduits along the right of way. Along the main line the underground conduit system consists of six three-inch conduits, part of which are clay and part bituminized fibre. These conduits are laid in concrete and manholes are provided every 400 feet. On top of this bank of conduit the main signal power feeder is carried in pump log conduit. This cable carries single-phase, 60 cycle current at a potential of 3400 volts. Telephone cables are paper insulated and lead covered. Telephone service is provided between all sub-stations and the power director and train dispatchers, and telephone boxes are located at all signal bridges. These signal bridges are only about one-half mile apart, so that ample facilities for communication are provided.

Car Inspection Building—A car inspection building has been provided in the Paoli yard. It was laid out to take care of not only the cars required for the present electrification, but those on the other divisions when electrified. Adjacent to this building is a small service plant containing boilers for heating, air compressors, motor-generators for supplying power for tools and lighting, and a motor-generator set for supplying emergency signal power.

Commutation and Commutation Limits*

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PROBABLY the most serious limitation encountered in direct-current electric machinery is that of commutation. This is an electrical problem primarily, but in carrying any design of direct-current machine to the utmost, certain limitations are found which, to a certain extent, are dependent upon the physical characteristics of materials, constructions, etc. In dealing with the limits of commutation, it is considered that the armature winding as a whole tends to set up a magnetic field when carrying current, and that the armature conductors cutting this magnetic field will generate e.m.fs. just as when cutting any magnetic field. From consideration of the armature magnetomotive force alone, the flux or field set up by this winding would have a maximum value over those armature conductors which are connected to the brushes. If the magnetic conditions or paths surrounding the armature were equally good at all points, this would be true. However, with the usual interpolar spaces in direct-current machines, the magnetic paths above the commutated coils are usually of higher reluctance than elsewhere. However, whatever the magnetic conditions, the tendency of the armature magnetomotive force is to establish magnetic fluxes and, if any field is established in the commutating zone by the armature winding, those armature coils cutting this field will have e.m.fs. generated in them proportional to the field which is cut. As part of this armature flux is across the armature slots themselves, and part is around the end windings, both of which are practically unaffected by the magnetic path in the interpolar space above referred to, obviously, no matter how poor the magnetic paths in the interpolar space above the core may be, there will always be e.m.fs. generated on account of that part of the armature flux which is not affected by those paths. In the coils short-circuited by the brushes, these e.m.fs. will naturally tend to set up local or short-circuit currents during the interval of short-circuit.

In good commutation, as the commutator bars connected to the two ends of an armature coil which is carrying current in a given direction pass under the brush, the current in the coil itself should die down at practically a uniform rate, to zero value at a point corresponding to the middle of the brush, and it should then increase at a uniform rate to its normal value in the opposite direction by the time that the short-circuit is opened as the coil passes from under the brush. This may be considered as ideal commutation.

If no corrective actions are present, the coil while under the brush tends to carry current in the same direction as before its terminals were short-circuited. In addition, the short-circuit current induced in the coil, due to cutting the armature flux, tends to add to the work current before reversal occurs. The resultant current in the coil thus tends to have an increased value, so that the conditions at the moment that the coil passes out from

*Based on a paper read before the American Institute of Electrical Engineers, Sept., 1915.

under the short-circuiting brush are much worse than if no short-circuit were generated, since the reversal of the current is almost instantaneous instead of being gradual as called for by the ideal commutation. However, the introduction of resistance into the local circuit greatly assists in the reversal.

The ideal condition is obtained by the introduction of an opposing e.m.f. into the local short-circuited path, thus neutralizing the tendency of the work current to continue in its former direction. As this opposing e.m.f. must be in the reverse direction, it follows that it is necessary to provide a magnetic field opposite in direction to the armature field for setting up the commutating current. This may be obtained in various ways, such as shifting the brushes forward (or backward) until the commutated coil comes under an external field of the right direction and value; or a special commutating field of the right direction and value may be provided. When shifting is used, only average conditions may be obtained for different loads; whereas, with suitable commutating poles, sufficiently correct commutating e.m.fs. can be obtained over a wide range of operation. In practice, it is difficult to obtain magnetic conditions such that an ideal neutralizing e.m.f. is generated. However, the use of a relatively high resistance in the short-circuited path of the commutated coil very greatly simplifies the problem. If the resistance of the coil itself were the only limit, then a relatively low magnetic field cut by the short-circuited coil would generate sufficient e.m.f. to circulate an excessively large local current. Since such current might be from 10 to 50 times as great as the normal work current, depending upon the size of machine, it would necessarily add to the difficulties of commutation whether it is in the same direction as the work current or in opposition.

To illustrate the effect of resistance, assume a short-circuit e.m.f. in the commutated coil of two volts, and also assume that a copper brush of negligible resistance short-circuits the coil, so that the resistance of the short-circuited coil itself practically limits the current to a value 20 times as large as the work current. Now replace this brush with one having 20 times the resistance of the coil. Then the total resistance in circuit is such that the short-circuit current is cut down to a value about equal to that of the work current. This at once gives a much easier condition of commutation, even without any reversing field. Thus a relatively high resistance brush—or brush contact—is of great help.

It is in its high contact resistance that the carbon brush is such an important factor in the commutating machine. Usually, it is the resistance of the brush that is referred to as an important factor in assisting commutation. In reality, it is the resistance of the contact between the brush and commutator face which must be considered, and not that of the brush itself, which usually is of much lower resistance, relatively.*

*The terms "brush resistance" and "brush drop" are used to indicate contact resistance and contact drop, respectively, unless otherwise specified.

SHORT-CIRCUIT VOLTS PER COMMUTATOR BAR

As stated before, the armature short-circuit e.m.f. per coil, or per commutator bar, is due to cutting a number of different magnetic fluxes, such as those of the end windings, those of the armature slots, and those over the armature core adjacent to the commutating zone. These fluxes represent different conditions and distributions, and therefore the individual e.m.fs. generated by them may not be coincident in time phase. Therefore, the resultant e.m.f. usually may not be represented by any simple graphical or mathematical expression.

When an external flux or field is superimposed on the armature in the commutating zone, it may be considered as setting up an additional e.m.f. which may be added to, or subtracted from, the resultant short-circuit e.m.f. due to the armature fluxes. For purposes of analysis, there are advantages in considering that all the e.m.fs. in the short-circuited armature coil are generated separately by the various fluxes. A better quantitative idea of the actions which are taking place is thus obtained, and the permissible limitations are more easily seen.† In practice, on account of the complexity of the separate elements which make up the apparent short-circuit e.m.f., it is very difficult, or in many cases, impossible, to neutralize or balance it entirely at all instants by means of an e.m.f. generated by an extraneous field or flux of a definite distribution. Therefore, it should be borne in mind that, in practice, only an approximate or average balance between the two component e.m.fs. is possible. With such average balance there are liable to be all sorts of minor pulsations in e.m.f. which tend to produce local currents and which must be taken care of by means of the brush resistance. Therefore, brushes of high enough resistance to take care of the short-circuit e.m.f. pulsations are a requisite of the present types of direct-current machines. These pulsating e.m.fs. will result in high frequency local currents, which have a harmful influence on commutation. They may be assumed to be roughly related in value to the apparent short-circuit volts generated by the armature conductor. As the currents set up by these pulsations must be limited largely by the brush contact resistance, it is obvious that there is a limit to the pulsations in voltage, beyond which the current set up by them may be harmful. Experience has shown that in commutating pole machines the apparent short-circuit voltages per turn may be as high as 4 to 4.5 volts, with usually but small evidence of local high frequency currents.

The contact drop between brush and commutator with the usual brushes is about 1 to 1.25 volts. The drop is not directly proportional to the current, but increases slowly with considerable increases in current. For instance, with 20 amperes per sq. in. in a given brush, the contact drop may be one volt; at 40 amperes it may be 1.25 volts, while at 100 amperes it may be 1.4

†As that component, due to cutting the various armature fluxes, will be referred to very frequently hereafter, it will be called the "apparent" armature short-circuit e.m.f. per coil, or in abbreviated form, "the apparent short-circuit e.m.f."

volts and, with materially higher currents, it may increase but little further. In some ways this peculiar property of the brush contact is very much of a disadvantage. For instance, if the local currents are to be limited to a comparatively low density, the voltages generating such currents must be kept comparatively low. With the above brush contact characteristics, two volts would allow a local current of 20 amperes per square inch to flow (there being one volt drop from brush to commutator and one volt back to the brush). If, however, the local voltage is three volts instead of two, or only 50 percent higher, then a local current of possibly 150 to 200 amperes per square inch may flow. It may be assumed in general that the lower the apparent short-circuit voltage per armature conductor, the lower the pulsations in this voltage are liable to be. Assuming, therefore, as a rough approximation a 50 percent pulsation as liable to occur, then, from the standpoint of brush contact drop, the total apparent voltage of the commutated coil in continuous service machines should not be more than 4 to 4.5 volts.

As the main advantage of the carbon brush is that it limits the amount of short-circuit current, it might be questioned whether such advantage might not be carried much further by using higher short-circuit voltages and proportionately greater resistance. However, there are reasons why this cannot be done. The carbon brush is a resistance in the path of the local current, but it is also in the path of the work current. As the brush resistance is increased, the greater is the short-circuit voltage which can be taken care of with a given limit in short-circuit current, but at the same time the loss due to the work current is increased. Decreasing the resistance of the brush contact increases the loss due to the short-circuit current, but decreases that due to the work current. Thus, in each individual case, there is some particular brush resistance which gives minimum loss. In some machines a low resistance brush is practicable, with consequent low loss due to work current. In other cases higher resistance brushes give better average results. In non-commutating pole machines where only average commutating fluxes are obtainable, the resistance of the brush is usually of more importance than in the commutating pole type, for in the latter a means is provided for controlling the value of the short-circuit current. However, advantage has been taken of this latter fact to such an extent in modern commutating pole machines that the critical or best brush resistance has again become a very important condition of design and operation.

"APPARENT" SHORT-CIRCUIT E.M.F. PER BRUSH

The preceding considerations lead up to another limitation, namely, the total e.m.f. short-circuited by the brush. This again may be considered as being made up of two components,—the average short-circuit e.m.f. per bar times the *average* number of bars covered by the brush, hereafter called "The apparent short-circuit e.m.f. per brush;" and the e.m.f. per bar generated by the commutating field times the average number of bars covered by the brush.

As has been shown, ordinary carbon brushes can short-circuit 2 to 2.5 volts without excessive local current. Obviously, if the resultant e.m.f. generated in all the coils short-circuited by the brush, that is, the resultant of the short-circuit e.m.fs. due to both the armature and the commutating field is much larger than 2.5 volts, large local currents will flow. Therefore, in a commutating pole machine, for instance, the strength of the commutating pole field should always be such that it also neutralizes the total short-circuit e.m.f. across the brush within a limit represented by the brush contact drop, in order to keep within the limits of permissible local currents. With very low resistance brushes, the proportioning of the commutating field for neutralization of the apparent brush e.m.f. would have to be much closer than with higher resistance brushes. Moreover, not only should this e.m.f. generated by the commutating flux balance the total short-circuit voltage across the brush within these prescribed limits, but these limits should not be exceeded anywhere under the brush.

It might be assumed that, if there is a pulsation of two volts per coil, the total pulsation would be equal to this value times the average number of coils short-circuited. However, this in general is not correct, as the e.m.f. pulsations for the different coils are not in phase, and their resultant may be but little larger than for a single coil. Based upon the foregoing considerations, the limiting values of the apparent brush e.m.f. may be approximated as follows: Assume ordinary carbon brushes with 1 to 1.25 volts drop with permissible current densities—that is, with 2 to 2.5 volts opposing action as regards local currents. Also assume, for example, an apparent brush short-circuit e.m.f. of 5 volts, with brush resistance sufficient to take care of 2.5 volts. Then the total e.m.f. due to the commutating flux need not be closer than 50 percent of the theoretically correct value, with permissible local currents. This is a comparatively easy condition, for it is a relatively poor design of machine in which the commutating pole strength cannot be brought within 50 percent of the correct value. Assuming next, an apparent e.m.f. of 10 volts, then the commutating pole must be proportioned within 25 percent of the right value. In practice, this also appears to be feasible, without undue care and refinement in proportioning the commutating field. If this machine never carried any overload this 25 percent approximation would represent a relatively easy condition, for experience has shown that proportioning within 10 percent is obtainable in some cases, which should allow an apparent brush e.m.f. of 25 volts as a limit. However, experience also shows that this latter is a comparatively sensitive condition which, while permissible on short peak loads, is not satisfactory for normal conditions. Where such close adjustment is necessary to keep within the brush correcting limits, any rapid changes in load are liable to result in sensitive commutating conditions, for the commu-

tating pole flux does not always rise and fall exactly in time with the armature flux, and thus momentary unbalanced conditions of possibly as high as 10 or 12 volts might occur with an apparent brush e.m.f. of 25 volts. Also, very slight saturation in the commutating pole magnetic circuit may have an unduly large influence on unbalancing the e.m.f. conditions. In other words, the apparent brush short-circuit and neutralizing e.m.fs. must not be unduly high compared with the permissible corrective drop of the brushes. Experience shows that an apparent e.m.f. of 10 volts across the brush in well-designed commutating pole machines is usually very satisfactory, while, in occasional cases, 12 to 13 volts give fair results on large machines and, in rare cases, as high as 15 to 18 volts have been allowed on small machines at normal rating. However, overloads, in some cases, limit this permissible apparent brush voltage. As a rule, 30 volts across the brush on extreme overload is permissible, but usually this is accompanied by some sparking. Under such overload conditions, doubtless unbalancing of three volts or more may be permissible, and thus, with 30 volts to be neutralized, this means about 90 percent theoretically correct proportioning of the commutating pole flux.

Usually it has been assumed that the decrease in contact resistance of carbon and graphite brushes with increase in temperature is in some ways related to the negative temperature coefficient of carbon and graphite. But this is not necessarily the case, for similar changes in the contact drop have been found with materials other than carbon, which actually had, in themselves, positive temperature coefficients. Moreover, in some tests, the changes in contact resistance with increase in temperature have proved to be much greater in proportion than occurs in the carbons themselves. In some cases the measured drops with temperature increases of less than 100 degrees C. decreased to one-half or one-third of the drops measured cold.

Obviously, these decreased contact resistances or drops may have a very considerable effect on the amount of local current which can flow and, therefore, in such cases, the foregoing general deductions should be modified accordingly. However, the results are so affected by the oxidation of the copper commutator face, and other conditions also more or less dependent upon temperature, that, as yet, no definite statement can be made regarding the practical effects of increase in temperature except the general one that the resistance is usually lowered to a considerable extent. Apparently, oxidation of the copper face tends toward higher contact resistance. Ofttimes "sanding off" the glaze tends to give poorer commutation. The above points to one explanation of this.

In the foregoing the limits for the apparent short-circuit e.m.f. per bar and per brush have been based upon the brush contact resistance. However, it may be suggested that something other than the brush contact resistance might be used for limiting the local current, and thus the commutating limits might be raised. For instance, an armature winding could be completely closed on itself, with high resistance leads carried from the winding to the commutator bars. Each of such leads would be in circuit only when the brushes touched the commutator bars. Thus there could be very considerable resistance in each lead without greatly increasing the total losses; and, unlike the brushes, each lead would be in circuit only for a very small proportion of the time.

About ten years ago the writer designed a non-commutating pole direct-current turbo-generator with such resistance leads connected between the winding and the commutator. The leads were placed in the armature slots below the main armature winding. The idea was to have sufficient resistance in circuit with the short-circuited coils so that the brushes at no load could be thrown well forward into a field flux sufficient to produce good commutation at heavy load, even if very low resistance brushes were used. Tests of this machine showed that the non-sparking range, with the brushes shifted either forward or back of the neutral point was very much greater than in an ordinary machine. In this case it developed that the leads were of too high resistance for practical purposes, as the armature ran too hot, the heat-dissipating conditions in a small direct-current turbo-armature not being any too good at best. These tests, however, indicate one possibility in the way of increasing the present limits of voltage per bar and volts across the brush. Moreover, such resistances can have a positive temperature coefficient of resistance, instead of the negative one of the carbon brushes and contacts. Also, the corrective action in limiting local currents would vary directly with the current over any range, and not reach a limit, as in carbon brushes.

Considerable experience with resistance leads in direct-current operation has also been obtained in large alternating-current commutator type railway motors, designed for operation on both alternating and direct-current circuits. Apparently these leads have a very appreciable balancing action as regards division of current between brush arms in parallel. With but few brushes per arm, it appears that very high current densities in the brushes can be used without undue glowing or honeycombing. Presumably the reduction in short-circuit current, when operating on direct current, also has much to do with this. Some special tests were made along this line, and it was found that a very low resistance in the leads, compared with that which was best for alternating-current operation, was sufficient to exert quite a decided balancing between the brush arms.

With properly proportioned resistance leads, it should be possible to use very low resistance brushes and relatively high current densities. Advantage of this might be taken in various ways. There may prove to be serious mechanical objections to such arrangements. However, if the objections are not too serious, the use of resistance leads in this manner may be practieed at some future time as more extreme designs are approached.

Small High-Speed Steam Turbines

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The steam turbine first achieved its prominence in the larger capacities. The first commercially successful machine was of 400 kilowatts normal capacity, and very soon turbines were built in sizes from that up to 10 000 kilowatts or more, in a few years replacing almost entirely reciprocating engines in these larger capacities where the service was the driving of alternating-current generators.

FIG. 1—VIEW SHOWING STEAM NOZZLE, ROTOR AND REVERSING CHAMBER

Naturally, the turbine builders began to consider the large field for units of small size. They were confronted with fundamental difficulties. The small turbine, in order to be economical, must run at high speed, and the various classes of apparatus to be driven, such as direct-current generators, pumps, blowers, etc., are comparatively slow-speed devices, limited in their speed not only by mechanical considerations, but on the score of efficiency also. The manufacturers, therefore, were confronted with this wide discrepancy in speeds between the turbine and the devices to be driven. The result was a compromise between the two, in which the manufacturer brought his turbine speed down lower than he wished to, and oftentimes the manufacturer of the driven device brought his speed up in excess of the ideal speed at which it should run. For this reason many small turbines were put in use which were fairly subject to the criticism of uneconomical operation. For a period, therefore, the small turbine was generally considered not to be competitive with the small reciprocating engine.

The field for small turbines was very large. Almost anyone would prefer a turbine to a reciprocating engine, from the standpoint of the type of prime mover alone: it was more reliable, it was much easier to operate, it took up less space, and essentially it would seem to be a less expensive machine to install. The problem, therefore, was to effect the desired improvement in economy. This was accomplished by the introduction of the reduction gear. Gears are operating now in all classes of service, in all sizes. Beyond any question, they have proved their mechanical sufficiency for any purpose. Their mechanical efficiency averages about 98 percent, the loss being negligible. The use of reduction gears permits both the turbine and the driven device to run at the speeds which will produce the highest economy, so that the application of the turbine to many purposes is now easily and successfully accomplished.

The prime requisites of a successful small turbine are simplicity and reliability of operation, good economy and a reasonable price. None of the well-known designs employed in large turbines met the requirements; if the steam consumption were kept down the price had of necessity to be high, and conversely if the price were reasonable the steam consumption was too high. These considerations led the designers of Westinghouse turbines to adopt for non-condensing service a type the general principles of which are shown in Fig. 1. A single wheel or disc, on which is mounted a single row of blades, constitutes the revolving element. High-pressure steam is admitted to the nozzle shown on the right of the wheel and is expanded in the nozzle to the pressure of the exhaust, the energy of the steam between the two pressures being transformed into velocity. Assuming saturated steam with an inlet pressure of 100 lbs. gage, and an exhaust pressure of 5 lbs. gage, the available heat drop is 130.7 B.t.u., which, when trans-

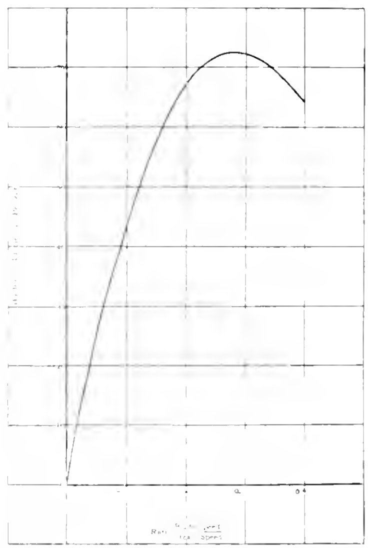

FIG. 2—CURVE SHOWING EFFICIENCY WITH VARYING RATIO OF BLADE SPEED TO STEAM SPEED

formed into velocity with a nozzle efficiency of 90 percent, is equivalent to 2290 feet per second. Steam at this velocity is directed by the nozzle against the blades of the revolving element which take up a part of the velocity, transforming it into work or power on the turbine shaft. The steam leaving the blades passes into the reversing

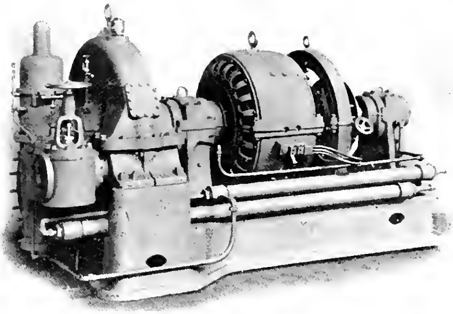

FIG. 3—100 KILOWATT, 2200 R.P.M., DIRECT-CURRENT TURBO-GENERATOR SET, DIRECT CONNECTED

chamber shown on the left of the wheel (Fig. 1), where its direction is reversed and it is again guided to the blades of the revolving element, through which it passes for the second time, giving up still more velocity which is converted into work. After passing through the blades the second time the steam leaves the turbine through the exhaust pipe.

As already indicated, turbines of this type were at first directly connected to the driven apparatus whose speed determined the speed of the unit. In practically every case this speed was lower than the desirable speed for the turbine, whose steam consumption was handicapped accordingly. How much this handicap amounted to may be determined approximately from Fig. 2, which shows the ratio of blade speed to steam speed plotted against the resulting efficiency, usually termed hydraulic efficiency. While the hydraulic efficiency alone does not determine the water rate of the turbine, it is by far the

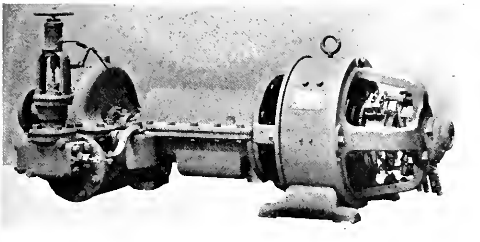

FIG. 4—SMALL GEARED DIRECT-CURRENT TURBO-GENERATOR SET

most important factor in the type of turbine discussed in this article. Referring to Fig. 2, it is seen that the maximum obtainable hydraulic efficiency (72.5 percent) is reached when the blade speed is 0.29 of the steam speed. If the operating conditions be 100 lbs. gage steam pressure and 5 lbs. gage back pressure, the steam speed, assuming 90 percent nozzle efficiency, will be [illegible] feet per second, and the ideal blade speed would be [illegible] feet per second. When limited to the speed of the driven apparatus, such a blade speed as this would mean that the turbine wheel or disc would have to be very large in diameter and consequently expensive. If the disc be made too large, another factor seriously affects

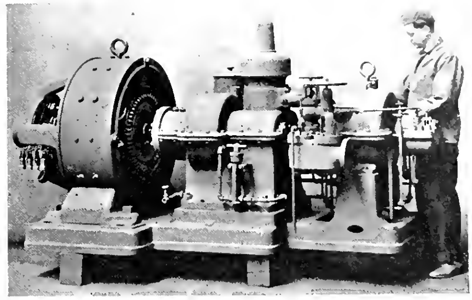

FIG. 5—DIRECT-CURRENT GEARED TURBO-GENERATOR SET WITH HAND-OPERATED NOZZLES

the water rate, namely, the friction loss caused by revolving a large disc at high peripheral speed in steam at the exhaust pressure. So serious does this loss become that if we use a disc greater than a certain diameter at a given speed, the loss due to friction of the disc is greater than the gain in hydraulic efficiency due to higher blade speed.

These facts made necessary a compromise in the case of directly-connected turbines and blade speeds considerably below the ideal were used. For example, the 100 kw unit shown in Fig. 3 runs at 2200 r.p.m. (the highest speed at which satisfactory commutation could be secured), had a mean diameter of 40.5 in. and a blade speed of 388 feet per second. With a steam pressure of 100 lbs. gage and 5 lbs. back pressure, the ratio of blade speed to steam speed was 0.169 and the resulting hydraulic efficiency 62.5 percent. The gain in efficiency due to lower disc friction is noteworthy. In the case of

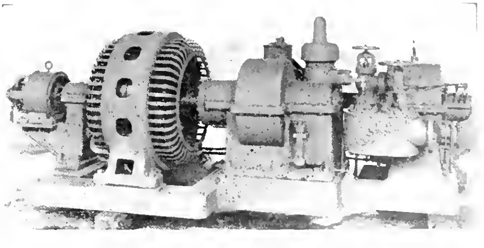

FIG. 6—ALTERNATING-CURRENT GEARED TURBO-GENERATOR SET

the 40.5 in. wheel at 388 feet blade speed, the disc friction was the equivalent of 12 brake hp. With the present design using a reduction gear the disc friction is only 3.8 hp.

The introduction of the high-speed reduction gear some years ago removed the chief difficulty under which

this type of turbine has struggled, that of limitation as to speed. The first reduction gear built by the Westinghouse companies was put into service early in 1910. It drove a 500 kw direct-current generator, the turbine speed being 3600 and the generator speed 720 r.p.m. Since that time the Westinghouse companies alone have installed, on order and building, an aggregate of more than quarter of a million horse-power, the capacity of the gears varying from 15 to 22 000 horse-power. They are used for many different purposes, from driving generators to driving the propellers on board ship.

Figs. 4, 5 and 6 show the latest types of small turbine-gear-generator units. In each case a turbine speed is chosen which will give practically ideal blade speed in combination with a disc or wheel of proper diameter, making a very efficient turbine. Standard generators of most suitable speed for high efficiency, good mechanical construction and moderate cost are used, and a reduction gear of the proper ratio to connect the two completes the set. Fig. 7 shows a cross-section through

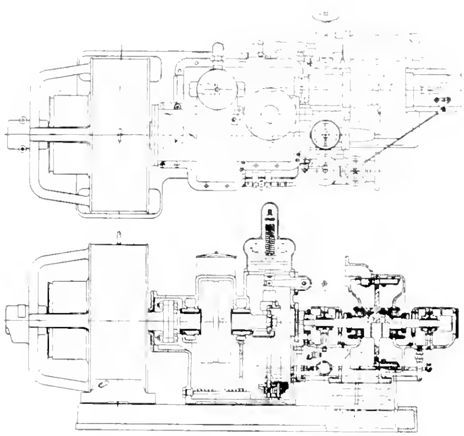

FIG. 7—PLAN AND VERTICAL SECTION OF TYPICAL GEARED SET WITH HAND-OPERATED NOZZLES

a typical machine. Several features of construction are worthy of special comment. The base of the gear case forms an oil reservoir for the whole unit. A simple cooling coil, through which water is circulated, keeps the oil at the proper temperature. The oil pump, which is immersed in oil and is driven by a hollow extension of the governor spindle from the gear shaft, pumps the oil through this hollow spindle, thoroughly lubricating the governor. The oil then flows to a strainer located on top of the gear case, and from this point it flows to the bearings by gravity and drains from there back into the bottom of the gear case, where it is cooled and recirculated. The oil may be replenished or a part of it drawn off for inspection while the unit is in operation.

All parts of the unit are easy of access for inspection or repair. The governor is of the well-known direct-acting flyball type, operating a throttling valve which maintains at the inlet to the nozzle the proper steam pressure to carry the load within the limits of the machine.

Steam to the turbine first passes through a hand-operated globe valve and then to a governor-controlled throttle valve. The steam after leaving the valve divides and passes to two hand-operated valves and thence to

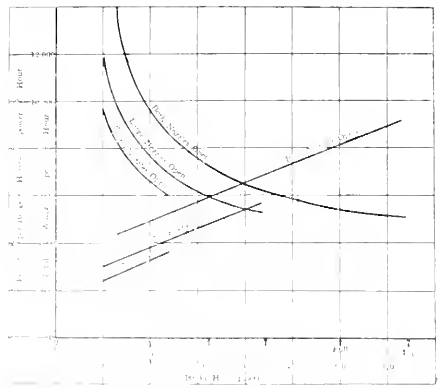

FIG. 8—WATER RATE CURVES WITH DIFFERENT NOZZLE OPENINGS

two sets of nozzles and reversing chambers. The relative capacities of these nozzles and reversing chambers may be designed within reasonable limits, to suit the requirements of the load, i. e., to give the minimum steam consumption under the load conditions to be met. By this scheme the turbine may be operated at light loads with a nozzle suitable for such loads. For heavier loads the other nozzle designed for the purpose is used. For overloads both nozzles are used. Fig. 8 shows the water rate of a 200 kw turbine generator unit (1) with both nozzles open, (2) with the larger nozzle only open, and (3) with the smaller nozzle only open. It will be seen that the water rates at light loads are notably good.

The field of the small high-speed turbine and reduction gear is by no means limited to the driving of electric generators. The same principles that make it excellent for electric drive apply with equal force to the driving

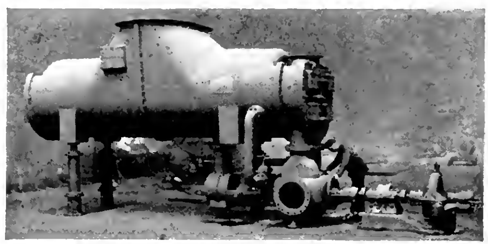

FIG. 9—CONDENSER PUMP GEARED TO TURBINE

of centrifugal pumps, blowers and other apparatus of moderate speed. Fig. 9 shows a turbine and gear driving the pumps of a surface condenser. The addition of the reduction gear in this case made the steam consumption of the turbine less than 60 percent of what it would have been had a directly-connected turbine been used.

Reconnecting Induction Motors

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THE necessity for considering a change in the characteristics of a power circuit supplying induction motors may arise naturally in a number of ways, as for example, moving a factory from one locality to another, discontinuing an isolated plant to buy central station power or raising the voltage on an overloaded distributing circuit to avoid the installation of heavier copper. These and similar good reasons give rise to queries regarding the adaptability of the old motors to the new conditions. It is not possible to keep within the bounds of reasonable, practical simplicity and still offer general formulae which will hold in all cases, but it is possible to cover in a fairly simple way certain general conditions and relations which have a bearing on any question of this nature. Considered in the order of their desirability, the possibilities in such cases are:—

1—Motor operated under new conditions without change.
2—Reconnection of the old windings to meet changed conditions.
3—Supplying a complete set of new coils
4—Supplying new laminations and also new coils.

An electric motor is a means for transforming energy in the form of an electric current into mechanical energy in the form of rotative force. This torque, or pull in pounds at one-foot radius, is produced by the force exerted by a current flowing in a conductor which is located in a magnetic field. It follows at once that the capacity of a motor to produce torque is limited both by the capacity of the copper circuit to carry current, or amperes, and the capacity of the iron circuit to carry magnetic lines of force, or flux. The heating of a motor depends upon the amount of current or flux which is being carried for a given cross-section of copper or iron. It may be assumed that in a normal motor operating under the conditions for which it was designed there is a reasonable current flowing in the copper and a reasonable flux in the iron which the designer believes will give the most satisfactory operating results. It follows, that if changes are to be made in the voltage, frequency, phase or speed at which the motor is to operate, the number of turns of copper must be changed or reconnected so as to preserve approximately the same amperes per square inch in the copper and the same flux density per square inch in the iron that existed in the motor before the change was made. This statement is true over a wide range of conditions, and would be true universally were it not for the fact that any rotating machine keeping the same current density in the copper and flux density in the iron will in general run hotter at slow speeds than at high on account of the reduced amount of cooling air which the machine can force through its own parts. For this reason it is generally true that the capacity of a motor may increase in the same proportion as the speed when the speed is being increased, but may decrease somewhat faster than the speed when the speed is being reduced. As a concrete example of this it may be stated that a 50 horse-power motor at 600 r.p.m. may be made to develop 100 horse-power at 1200 r.p.m., assuming that the mechanical design would stand the increased stresses due to the increased speed, but conversely, a motor originally designed for 100 horse-power at 1200 r.p.m. when cut down to 600 r.p.m. might not develop more than 40 horse-power on account of reduced ventilation.

It is the object of this article to describe briefly what questions must be considered to determine whether the characteristics of a motor may be changed in the manner desired; second, what the effect will be on the windings of the motor with respect to the number of turns in the coils and the mechanical form of the coils, and third, by what simple mechanical means, such as reconnection, if possible, the desired change may be accomplished.

There are certain simple fundamental mechanical relations which govern all motors, whether alternating or direct current. The idea given above of the reaction of the electric current upon the magnetic field concerns the production of a mechanical pull tending to rotate the movable member of the motor. This pull is usually expressed in pounds at one-foot radius. This in turn is expressed in horse-power when multiplied by the r.p.m. and by 2π and divided by 33 000. As expressed in an equation this is

$$\textit{Horse-power} = \frac{\textit{Torque} \times \textit{r.p.m.} \times 2\pi}{33\,000} = \frac{\textit{Torque} \times \textit{r.p.m.}}{5252}$$

and conversely,

$$\textit{Torque} = \frac{\textit{Horse-power} \times 5252}{\textit{r.p.m.}}$$

It has been stated that torque is proportional to the current in the conductors and flux in the iron, and also that in changing the motor these quantities should be kept as nearly as possible constant. The latter statement is equivalent to saying that the torque will be kept constant, and therefore that the horse-power will vary directly with the r.p.m. This is another way of saying that while the iron and the copper in the motor are working just as hard and carrying the same flux and the same current at all times, there will be developed twice the horse-power at twice the speed, or roughly, half the horse-power at half the speed.

It is essential in getting a clear conception of a motor, either for purposes of making changes as at present or for other reasons, that a plain distinction be made between torque and horse-power. It is the function of a motor to produce torque or rotative force; it is incidental that when this same force is allowed to rotate at one speed or another a different horse-power is pro-

duced. For this reason it is incorrect in speaking of a motor to say "It required 20 horse-power to start the load," because, when starting, the motor was practically at a standstill—there was no rotation, and hence no horse-power. The motor, however, was taking current and developing torque, and the correct expression would be, "The current taken at start was equivalent to the current when developing 20 horse-power after the motor is up to speed."

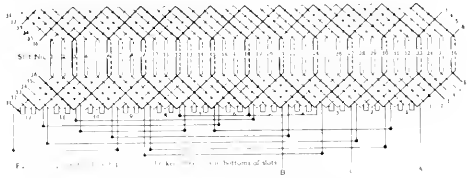


FIG. 1—DEVELOPED THREE-PHASE WINDING
Thirty-six slots, four poles, series-star.

There is another simple physical idea that is perhaps more useful than any other in keeping a clear idea of changes in motor windings. This is that either a direct-current motor or an induction motor is acting as a generator, aside from and in addition to its motor action. To think of this it is necessary to forget for the time the torque action between a conductor carrying current in a magnetic field and think of the same conductor moving across that field and so cutting the flux and generating voltage. The cycle of action up to this point is as follows:—First, the magnetic field is set up; second, current flows in the conductors, producing torque; and third, that torque moves the conductors across the field and this generates a voltage. This latter voltage is commonly called counter electromotive-force, and in all cases is practically equal to the line or applied voltage, except for a small loss in the motor caused by producing the torque. It follows at once that designing a motor is primarily designing a generator for the line voltage. With this conception and the fundamental formula for electromotive-force, it is a simple matter to write expressions showing how the turns in a motor should vary with different line voltages and for different speeds, etc.

These are matters with which the designing engineer is chiefly concerned, but they are sufficiently simple to be borne in mind at all times and in themselves offer the readiest first-hand answer as to the probable result of operating a motor under changed conditions. Before passing to the various changes in detail it is desirable to make a classification of the possible changes which may be made.

CLASSIFICATION OF CHANGES

Some changes can be made which in their nature leave the motor entirely normal and the performance in all essential respects remains the same as before reconnection. Such changes, for example, are represented by connecting the polar groups of a winding in series for 440 volts and in parallel for 220 volts. For convenience these are called class *A* changes.

A second class of changes leaves the performance in some respects unchanged and alters it in others. These may be represented by operating a motor in star on 440 volts, as in Fig. 3, and in delta for 220 volts, as in Fig. 6. In this case there is little change in efficiency or power-factor; the starting and maximum torques, however, are only 75 percent of their original values. In such a case the advisability of the change depends entirely on the work that the motor is doing. If the torques at their altered values are sufficient to start and carry the driven load easily there is no objection to operating the motor indefinitely as so reconnected, since the motor will not run any warmer than before and its efficiency and power-factor may be better. Such changes are classified as *B* changes.

A third class of changes leaves a motor operative in the sense of producing torque enough to do the work required, but so alters its performance as to heating, or efficiency, or power-factor, or insulation, that it is undesirable to leave the motor operating indefinitely in such condition. Such changes are represented by taking a three-phase motor and reconnecting the coils as they stand for two-phase. This is equivalent to operating the three-phase motor at 125 percent normal voltage and, in addition, the coils, which should have extra insulation where the phases change, have only group insulation, as explained under "phase insulation" The iron loss and heating may be increased to a dangerous degree and the power-factor greatly decreased. Such changes should only be used in an emergency and the proper permanent changes made at as early a date as possible. These are class *C* changes.

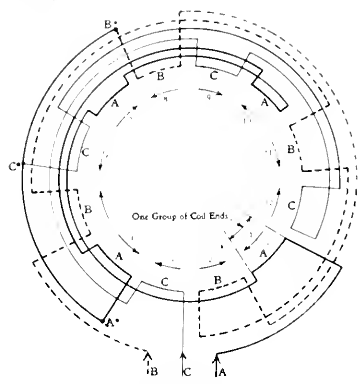


FIG. 2—CONVENTIONAL DIAGRAMATIC SKETCH OF WINDING SHOWN IN FIG. 1

In discussing the various changes frequent reference is made to the usual forms of connections. For this reason certain typical diagrams are illustrated.

TYPICAL DIAGRAMS

The diagrams shown in the cuts in this article are typical of those in general use by all motor manufacturers. They are by no means complete in the sense of covering all possible combinations of phases and poles,

but they serve to illustrate the points brought out in the text and are sufficiently general to cover points which may arise in connection with similar diagrams for other numbers of poles.

Fig. 1 gives a development of a three-phase, four-pole winding connected in series star. It is taken from a 36 slot core and represents the coils as they would look if removed from the machine and laid on a table with the connections as they exist in the machine. Since there are $3 \times 4 = 12$ polar groups and 36 coils, there are three coils connected in series to form a polar phase group. It should be borne in mind that there are not actually 12 magnetic poles in the machine, for the reason that three consecutive polar phase groups unite to form one magnetic pole by virtue of the phase difference of the currents in the three phases. Considered magnetically, there are two north and two south poles formed by this winding at any instant, and these poles are equally spaced around the air-gap just as is the case with four mechanically projecting pole pieces excited by four coils carrying direct current. Something of this conception is gained if one imagines the armature of a direct-current generator held stationary and the field poles rotated around it. At any given instant the magnetic field can be conceived to be the same as the field which is formed by the winding shown in Fig. 1. The coils in slots *3, 6, 9, 12*, etc., are shown by heavier lines to indicate that the insulation on these coils is heavier to withstand the greater strain at the points where the winding crosses or lies adjacent to coils differing greatly in potential. This is the so-called "phase insulation," and may be put on the first coil in each group, or it may be put on the first and last coil of each group where there are a greater number of coils in the group. This is one of the reasons why a machine may not at times be reconnected for another number of poles or phases.

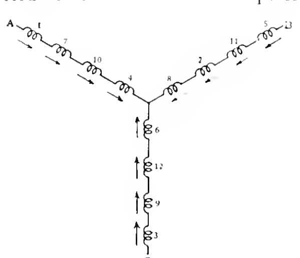


FIG. 3—SCHEMATIC DIAGRAM OF SERIES-STAR, FOUR-POLE WINDING
Showing the same connections as Figs 1 and 2. The numerals indicate the corresponding pole groups.

If such reconnection were made the maximum differences in potential might occur between two adjacent coils unprotected by this extra insulation and a breakdown result.

Since it is difficult to represent windings in such detail as Fig. 1, a conventional method of giving the same information is adopted. This scheme is shown in Fig. 2. This represents the same connection as Fig. 1, except that each phase pole group as numbered *1, 2, 3*, etc., in Fig. 1 is shown by a short arc in Fig. 2. The numbers on the groups are identical with Fig. 1, as are the group connections. The arrows are shown simply to indicate a method of checking up to insure the proper phase relations. There is considerable danger with a three-phase connection of getting a 60 degree relation between the phases instead of a 120 degree relation or, as it might be expressed on the diagram, there is danger that the wrong end of the *B* phase, for example,

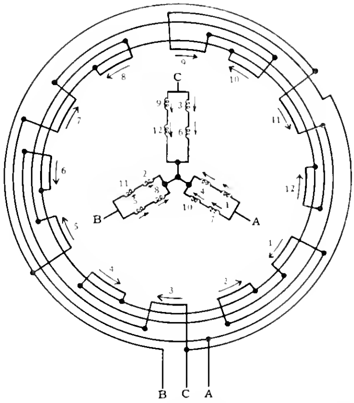


FIG. 4—CONVENTIONAL THREE-PHASE, FOUR-POLE, PARALLEL STAR DIAGRAM
And schematic equivalent.

may be connected to the star point. As a check against this, when the diagram is completed, the current is assumed as going in at all three leads toward the *Y* point. Arrows are put on each pole phase group as shown, and when all three phases are traced through the winding is correct if the arrows on consecutive groups run alternately clockwise and counter clockwise. It may be argued that this is an artificial assumption and that at no instant is the current flowing toward the star in all three phases. It may also be argued that in a correct winding, if the current be assumed as flowing toward the star in two phases and always from it in the third, the arrows will fall in successive flights of three in the same direction and then three in the reverse direction. These statements are true, but a little experimenting will show that an incorrectly connected or 60 degree winding can in this way be shown to give successive flights of three arrows and still be wrong. There is but one exception to the correctness of the check as shown in Figs. 2 and 3 and succeeding figures where the current is assumed as flowing toward the star in all three phases and the arrows alternate in direction. This exception to the rule is the case where the winding forms consequent poles or passes through all the phase pole groups in a north direction instead of alternately north and south. Such connections are rarely used, and then usually on special motors wound for multi-speeds.

The same connection shown in Figs. 1 and 2 is indicated schematically in Fig. 3, and the numbers of the

phase pole groups are identically arranged. The arrows indicate the phase polarity check test just described. Of these three schemes Fig. 1 may be said to be the winder's conception, Fig. 2 the draftman's and Fig. 3 the engineer's. Each serves its purpose, as any one of the three may be more easily grasped by a given individual. Fig. 4

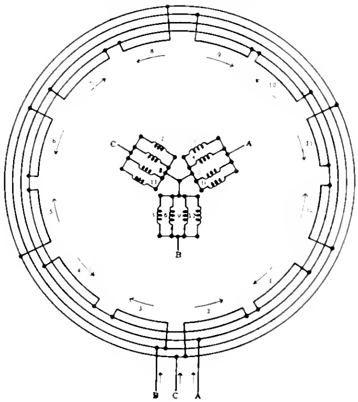


FIG. 5—THREE-PHASE, FOUR-POLE, FOUR-PARALLEL, STAR DIAGRAM
And schematic equivalent.

gives a combined conventional and schematic representation of a so-called "parallel star" diagram, where the two halves of each phase are in parallel. If a given machine were connected, as shown in Fig. 2, for a normal voltage of 440, it could readily be reconnected according to Fig. 4, and would then be suitable for operation on 220 volts having the same performance in all respects except that it would draw from the 220 volt line twice as many amperes under a given load as it previously drew from the 440 volt line. Similarly, if it had four poles, or a multiple of four poles, it could still be

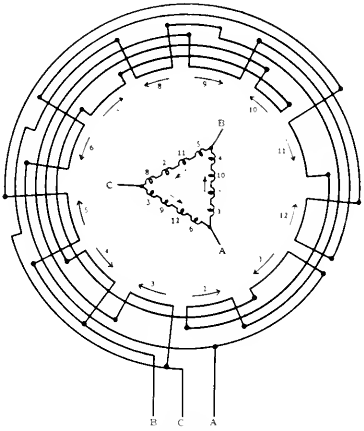


FIG. 6—THREE-PHASE, FOUR-POLE, SERIES DELTA DIAGRAM
And schematic equivalent.

parallelled again, or put in 4-parallel star, as shown in Fig. 5, and operated on 110 volts, and would still have the same performance at a correspondingly increased current at the same load.

Fig. 6 represents a variation in connection from the foregoing, which is possible only with three-phase machines. This is the so-called delta or mesh connection. If a machine connected as in Fig. 1 for 440 volts be reconnected as in Fig. 6 it would be suitable for operation on a circuit having a voltage of $\frac{440}{1.73}$, or 254 volts. Reconnections or conversions of this kind are intended to be shown in Table I, where the problem just shown may be worked out by selecting *3 Phase Series Star* in the horizontal column—first line—and reading across to the vertical column headed *Series Delta* where the figure 58 appears. This means that if 100 volts was normal on the series star connection and a change is made to series delta the corresponding voltage is 58 and by multiplication, if 440 was the series star voltage, the series delta voltage would be $4.4 \times 58 = 254$, as noted above. Figs. 7 and 8 show a parallel and 4-parallel delta connection, respectively, and bear the same relation to Fig. 6 that Figs. 4 and 5 do to Fig. 2.

TABLE I—COMPARISON OF MOTOR VOLTAGES WITH VARIOUS CONNECTIONS

If a motor connected originally as shown in any horizontal column had a normal voltage of 100 its voltage when reconnected as indicated in any vertical column is shown at the intersection of the two columns.

	3-Ph. Series Star	3-Ph. 2-Par. Star	3-Ph. 3-Par. Star	3-Ph. 4-Par. Star	3-Ph. 5-Par. Star	3-Ph. Series Delta	3-Ph. 2-Par. Delta	3-Ph. 3-Par. Delta	3-Ph. 4-Par. Delta	3-Ph. 5-Par. Delta	2-Ph. Series	2-Ph 2-Par.	2-Ph. 3-Par.	2-Ph. 4-Par.	2-Ph. 5-Par
3-Phase Series Star	100	50	33	25	20	58	29	19	15	12	81	41	27	20	16
3-Phase 2-Parallel Star	200	100	67	50	40	116	58	38	29	23	162	81	54	40	32
3-Phase 3-Parallel Star	300	150	100	75	60	174	87	57	44	35	243	122	81	60	48
3-Phase 4-Parallel Star	400	200	133	100	80	232	116	76	58	46	324	163	108	80	64
3-Phase 5-Parallel Star	500	250	165	125	100	290	145	95	73	58	405	203	135	100	80
3-Phase Series Delta	173	86	58	43	35	100	50	33	25	20	140	70	47	35	28
3-Phase 2-Par. Delta	346	172	116	86	70	200	100	66	50	40	280	140	94	70	56
3-Phase 3-Par. Delta	519	258	174	129	105	300	150	100	75	60	420	210	141	105	84
3-Phase 4-Par Delta	692	344	232	172	140	400	200	133	100	80	560	280	188	140	112
3-Phase 5-Par. Delta	865	430	290	215	175	500	250	165	125	100	700	350	235	175	140
2-Phase Series	125	63	42	31	25	73	37	24	18	15	100	50	33	25	20
2-Phase 2-Parallels	250	125	84	63	50	146	73	49	37	29	200	100	67	50	40
2-Phase 3-Parallels	375	188	125	94	75	219	110	73	55	44	300	150	100	75	60
2-Phase 4-Parallels	500	250	167	125	100	292	146	97	73	58	400	200	133	100	80
2-Phase 5-Parallels	625	313	208	156	125	365	183	122	91	73	500	250	167	125	100

Fig. 9 is a development of a two-phase winding and shows an arrangement similar to Fig. 1, except for the difference in the number of phases. An inspection of the coils represented in heavier lines and a comparison with the coils in Fig. 1 indicates at once what is meant by the "phase coils" or phase insulated coils being differently situated. This also explains one of the good reasons why two-phase motors should not be reconnected for three-phase, or vice versa, without changing the position of these phase coils.

Fig. 10 gives the conventional and schematic equivalent of Fig. 9. The arrows shown in the three-phase diagrams are omitted here, for the reason that the two phases are not interconnected, and the only effect of reversing one phase is to reverse the direction of rotation of the motor. This is readily corrected by reversing the two leads of one phase at the motor terminals. Figs. 11 and 12 give parallel and 4-parallel two-phase connections and bear the same relation to the series connection as was the case in the three-phase star and delta diagrams. From these 2-parallel and 4-parallel connections it may be readily seen that where the number of poles is a multiple of three, as 6, 12, 18, etc., there is a possible analogous 3-parallel connection; also where the number of poles is a multiple of five, such as 10, 20, etc., there is a corresponding possible 5-parallel diagram.

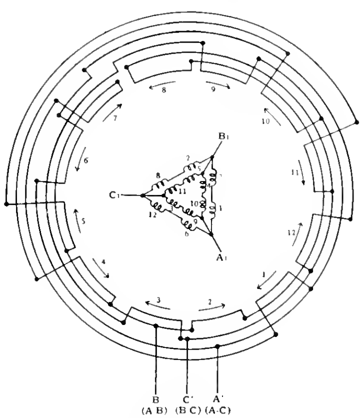


FIG. 7—THREE-PHASE, FOUR-POLE, PARALLEL DELTA DIAGRAM
And schematic equivalent.

TABLE II—COMPARATIVE PERFORMANCES

Of a two-phase motor reconnected for operation on three-phase by a *T* connection and the performance of the same motor when supplied with new three-phase coils and connected in a normal three-phase manner.

	Normal Two Phase Winding	Three Phase "Tee" Connection	Normal Three Phase Winding
Full-load Efficiency. . .	88	86.9	88.5
Full-load Power-Factor	89	84.8	90
Starting Torque.	1.75	1.20	1.94
Maximum Torque.	3.3	3.17	3.3
DEGREES CENTIGRADE RISE AT FULL LOAD			
Stator Copper. .	22.5°	32°	21°
Stator Iron . . .	20	32.5	19
Rotor Copper.	22	30	22

These are the connections which are indicated in Table I as "3-parallel" and "5-parallel."

Fig. 13 shows a possible three-phase connection which may be made from a two-phase winding by a method similar to the Scott transformer connection. The effect of this connection upon the performance is shown in Table II and is discussed under changes in phase. It is a connection which should be used only as a temporary expedient until better arrangements can be made.

Fig. 14 shows an interesting connection, called by a late author a "vernier" or "least common multiple" connection, in which the number of slots in the machine is not a multiple of the phase times the poles. As a result, there are more coils in certain groups than in others, which introduces a slight displacement of the phase angle at these places. They are so disposed around the machine, however, as to produce a perfectly balanced voltage at the terminals of the machine. This connection has been used for many years by the manufacturers, and is the result of using the same punching or stamping and winding it for the greatest possible number of combinations of phases and poles. For some time the extra coils were arranged around the machine by inspection to secure the best balance. Mr. E. M. Tingley has given an ingenious and simple method for arranging such windings with mathematical accuracy to give perfectly balanced voltages.* It does not follow that only

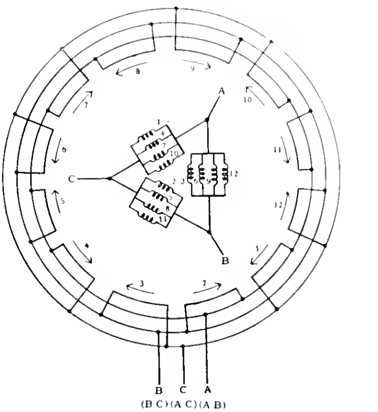


FIG. 8—THREE-PHASE, FOUR-POLE, FOUR-PARALLEL, DELTA DIAGRAM
And schematic equivalent.

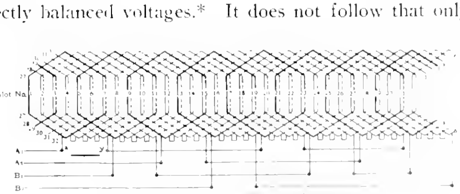


FIG. 9—DEVELOPED TWO-PHASE WINDING, FOUR-POLE, SERIES CONNECTION
The coils from *x* to *y* form one-pole phase group

the slot numbers recommended by Mr. Tingley can be made to give operating results, but it is true that only the combinations pointed out by him can be made to give a theoretically perfect voltage balance at the motor ter-

*In the *Electrical Review* for January 23, 1915, Vol. LXVI pp. 166-7-8.

minals. This diagram is shown to answer the question frequently asked as to whether it is essential that the number of primary slots shall be a multiple of the phase times the poles. It does not necessarily have to be such a multiple, and connections of the general type shown in Fig. 14 give practically the same results as any of the perfectly symmetrical connections.

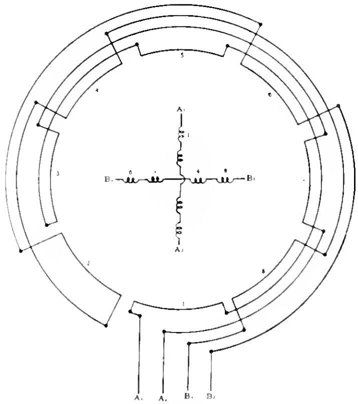


FIG. 10—TWO-PHASE, FOUR-POLE, SERIES CONNECTION
And schematic equivalent.

Figs. 15 and 17 show the usual connections for a three-phase motor which can be connected to give two sets of poles or two speeds in the ratio of two to one. This change is accomplished by a single winding. In Fig. 15 the high-speed is parallel star and the low-speed series star. In Fig. 17 the high-speed is parallel star and the low-speed series delta. Either may be used at the discretion of the designer. Fig. 15 usually gives better results where a constant torque is desired and gives twice the horse-power on the high-speed that it develops on the low-speed. Fig. 17 gives somewhat better results where a constant horse-power is desired at both speeds, as is the case with most machine tool applications. Fig. 16 is an explanatory diagram showing schematically how the two sets of poles are produced by such windings. Considered with Fig. 15, the inside set of arrows show the parallel star connection where four salient poles are produced directly by the winding, two north and two south. The set of arrows outside the winding circle show the winding connected in series star and the current direction such as to produce four north poles by the winding. Since it is not possible to have north poles alone there immediately result four consequent south poles, indicated by the dotted arrows, where the magnetic flux returns to the primary. This results in eight poles and half speed. For the sake of simplicity the arrows shown are for one phase only. The three phases interact to produce the combined magnetic pole as in any normal three-phase winding. These diagrams are shown to indicate that it may be possible in some cases to reconnect motors for half speed by making use of a diagram of this nature.

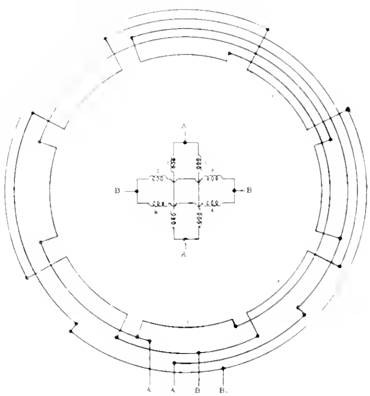


FIG. 11—TWO-PHASE, FOUR-POLE, PARALLEL DIAGRAM
And schematic equivalent.

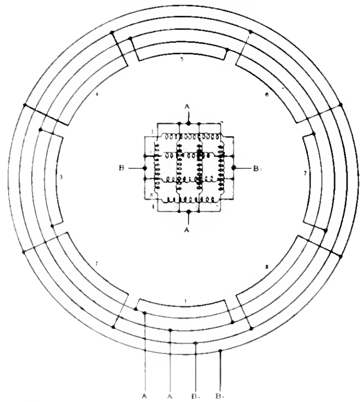


FIG. 12—TWO-PHASE, FOUR-POLE, FOUR-PARALLEL DIAGRAM
And schematic equivalent.

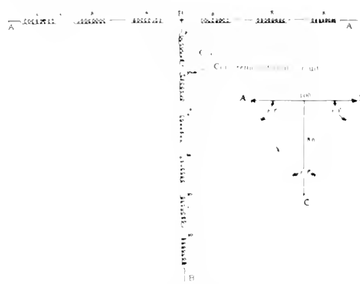


FIG. 13—SO-CALLED *T* CONNECTION
By which a two-phase motor may be operated on three phase at a reduced capacity and somewhat poorer efficiency, power-factor and torques.

Fig. 18 shows a similar diagram for a two-phase, two-speed connection where the winding is in parallel on the high-speed and in series on the low-speed. This winding is of particular and especial interest in that it overcomes one of the disadvantages of the correspond-

ing three-phase connections shown in Figs. 15 and 17 by putting half of the winding in one phase for the low-speed connection and in the other phase for the high-speed connection. This is of advantage, because the so-called "winding factor" or "distribution factor" remains

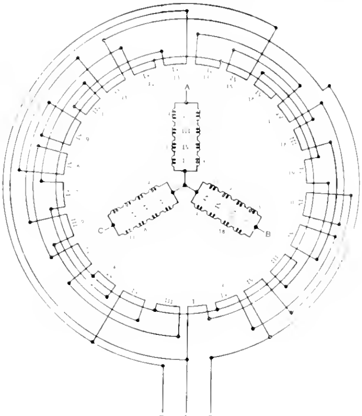


FIG. 14—THREE-PHASE, EIGHT-POLE, PARALLEL STAR DIAGRAM
With balanced phases on a machine having 90 slots. The number of coils in each pole phase is shown by the Roman numerals.

the same on both speeds as in a normal two-phase machine, while in the three-phase connections shown in Figs. 15 and 17 the winding factor is only 86.6 percent as good on the low-speed connection as on the high. This is because there are only four winding groups per phase spread over the entire periphery and yet eight poles are being produced. Expressed in another way, the coils for one of the eight poles are spread over the usual span for a four-pole machine. Since the distribution factor is a measure of the induced voltage or counter e.m.f. generated, and since the capacity of the motor may be measured by its current carrying capacity multiplied by the induced voltage, it can be concluded at once that the loss of 14.3 percent in the three-phase connection on the slow-speed is avoided in the two-phase diagram, Fig. 18. In reality the gain is greater than this, for the reason that the two-phase distribution factor caused by consequent poles is only 70.7 percent, as

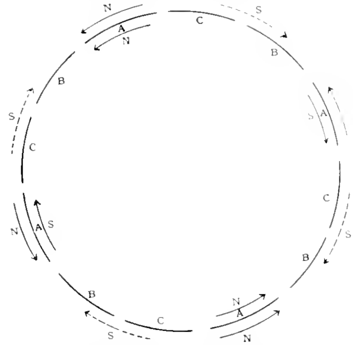


FIG. 16—DIAGRAM ILLUSTRATING LOCATION OF POLES IN TWO-SPEED CONNECTION SHOWN IN FIG. 15

The arrows inside the winding circle show the poles formed by the A phase windings on the four-pole connection. The arrows outside the circle show the four poles of the same polarity formed by the windings, and the four resulting consequent poles of opposite polarity are shown by the dotted arrows; this makes eight poles total and gives half the speed of the four-pole connection.

against 86.6 percent in the three-phase. Speaking simply, if a series parallel two-phase connection were used, similar to the three-phase, Fig. 15, and without changing the coils from one phase to the other as does Fig. 18, the loss in horse-power on the slow-speed would be approximately 30 percent, which is certainly a matter of prime importance. It is mechanically possible to make such an arrangement on a two-phase winding, but there seems to be no practical way of accomplishing the same result on a three-phase winding. As in the case of

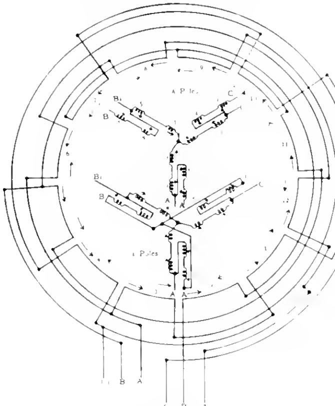


FIG. 15—THREE-PHASE, TWO-SPEED, FOUR AND EIGHT POLE DIAGRAM
Parallel star connection for four poles. Series star connection for eight poles. On four poles A_1—B_1—C_1 are leads and A—B—C are connected together. On eight poles A—B—C are leads and A_1—B_1—C_1 are open.

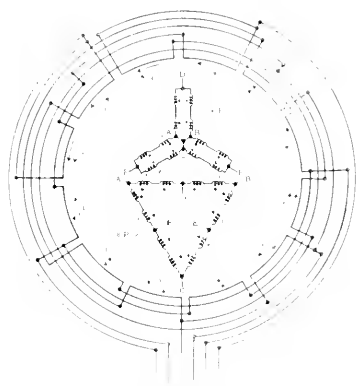


FIG. 17—THREE-PHASE, TWO-SPEED, FOUR AND EIGHT POLE DIAGRAM
Parallel star connection for four poles. Series delta connection for eight poles. On four poles D—E—F are leads and A—B—C are connected together. On eight poles A—B—C are leads and D—E—F are open

the three-phase, two-speed diagrams, this connection shows the possibility of changing a standard motor to half speed by the medium of such a connection.

Fig. 19 illustrates a connection that is sometimes attempted, but usually with disastrous results. In all the foregoing diagrams the phase pole group has been

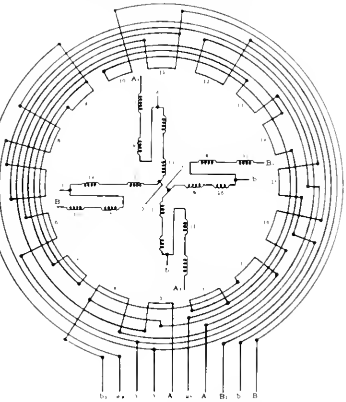


FIG. 18—TWO-PHASE, TWO-SPEED, FOUR AND EIGHT POLE DIAGRAM

For eight poles connect y and y'. Use A_1—A_2 and B_1—B_2 for leads and leave a_1—a_2 and b_1—b_2 open. For four poles connect A_1—B_1 together and A_2—B_2 together; leave y and y' open and use a_1—a_2 and b_1—b_2 for leads.

treated as a unit. That is to say, if there were four coils per phase and pole these four were connected in series into a group and handled as a unit. Fig 19, on the other hand, breaks up some of the groups into halves. Suppose, for example, that a three-phase, six-pole motor has 72 coils total and is connected in series for 440 volts. It is desired to reconnect it for 110 volts. It can be paralleled for 220 volts, and there will be three-pole phase groups in each of the two parallel legs of the winding. It cannot be parallel four times, since six is not divisible exactly by four. Since there are six poles and three phases, there are 18 pole phase groups and $72 \div 18 = 4$ coils per group. It is, therefore, possible to split six of the 18 groups into halves of two coils each, and by putting a half group in series with a whole group to get four parallels per phase having 1.5 pole-phase groups in each of the four parallel circuits. Such a connection is shown in Fig. 19. This is rather difficult to do properly unless there is an expert winder available, and it leaves the motor in an unsatisfactory operating condition when it has been done. This is explained by the vector diagrams in Figs. 20 to 24. Let *ag* represent the vector of one magnetic pole made by combining the three-pole phase vectors *ac*, *cf* and *fg*, Fig. 20. For clearness, one-pole phase vector *ae* is shown in Fig. 21 drawn to a larger scale and made up of the vectors of the four separate coils *ab*, *bc*, *cd* and *de*. If two or more circuits, each made up of one whole pole plus one-half pole, are to be connected in parallel, the two resulting vectors should be the same length and have the same direction or phase. Such a condition is shown in Fig. 22. This is a true parallel, and there will be no circulating current around the closed loop, since two equal voltages in phase with each other are opposed. An inspection of the four vectors of which *ae* is composed will show that it cannot readily be divided into two parts and paralleled without there being circulating current. Suppose first, that the winding group is split in the middle at *C*, leaving *ab* + *bc* for one-half and *cd* + *de* for the other. The two resulting vectors are *ac* and *ce*. When each of these vectors is added to another complete pole and the two connected in parallel, the result is indicated in Fig. 24, where *ra* + *ac* is paralleled with *sc* + *ce*. Since *ac* and *ce* are not in phase there is left a voltage equivalent to *cm* + *nc*, which will set up current around the closed loop and produce increased heating. In order to avoid this to a certain extent the two outside coils of the group, *ab* and *de*, are sometimes paralleled against the two inside coils, *bc* and *cd*. The two resulting vectors *ax* + *ze* and *bd* are in parallel, but they are of different lengths. The result is shown in Fig. 24, where a whole pole *tb* plus the half pole *bd* is in parallel with *ra* + *ax* + *ze*. While these vectors are in phase the difference in their numerical value leaves a component *ek* which is unbalanced and which is free to cause circulating current in the closed loop of the parallel circuit.

In addition to the difficulty of making this connection properly and the fact that there is at all times some circulating current, there is also likely to be trouble in keeping the phases insulated from each other. All things considered, this is an expedient which had better be left untried except in cases of emergency. For all ordinary operating conditions much better results will

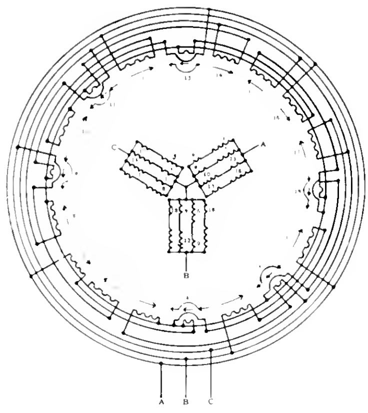


FIG. 19—THREE-PHASE, SIX-POLE, STAR DIAGRAM IN FOUR PARALLELS

Diagrams of this general type should be used only in cases of temporary emergency.

be secured by replacing the old coils in the machine by new coils wound for the proper voltage.

CHORD FACTOR AND PHASE INSULATION

Before considering the more useful forms of reconnection there are two general factors which should be

mentioned as having a great deal to do with the possibility of reconnecting and also with the operating characteristics of the motor after the change is made. The first of these is the throw of the individual coils or the number of slots spanned by the two sides of the coil. The second is the question of phase insulation mentioned above and shown in Figs. 1 and 9. The first of these questions has been generally written about and discussed under the headings, "Fractional Pitch Windings" and "Chorded Windings."* Only a brief mention can be made here of the effect of this condition on reconnection.

It is well known that the span of the coil must in general be somewhere near the quotient of the bore periphery divided by the number of poles. It is not so generally understood that changing the span of the coil within limits has an effect similar to increasing or decreasing the number of wires in the coil. If the coil is exactly pitch, i. e., spans exactly from the center of one pole to the center of the next, the turns of wire in that coil are producing their maximum effect upon the magnetic field. The coil is then considered to span 180 electrical degrees. It is customary to wind the coil in slots so that it spans something less than a full pole pitch. The effect of the turns in the coil is then somewhat less than the maximum. The effect of the turns in the coil varies as the sine of half of the angle in electrical degrees which the coil spans. To illustrate, if there are 72 slots in an eight-pole machine, the coils would be exactly "pitch" if they lay in slots 1 and 10, or in other words, if there were eight slots between the two slots in which the two sides of any coil were located. Such a coil would span 180 electrical degrees. Half of 180 degrees is 90 degrees and the sine of 90 degrees is 1; therefore the effect of the turns in such a coil is 1. Suppose instead the coil lies in slots 1 and 8. It would then span 140 degrees electrically, since $72 \div 8 = 9$ slots represents 180 degrees, and one slot therefore represents 20 degrees. The sine of half of 140 degrees, or 70 degrees, is 0.938. It follows that the effect of the turns in this coil is less than that of the full pitch coil by the ratio of 0.938 to 1. This is of interest in the present problem, because it is often possible in making changes to change at the same time the span of the coils by one slot, more or less, by springing the coil mechanically, and so improve the performance of the machine under the new conditions. The point becomes of vital importance, immediately, when changing the number of poles without changing the throw of the coils. Referring again to the 72 slot motor, assume that the coils are wound in slots 1 and 8. For an 8 pole connection these coils will have an effect of 0.938, as explained above. If the connections are changed for six poles the effect is entirely different. $72 \div 6 = 12$ and $180 \div 12 = 15$, or each slot represents 15 electrical degrees. A throw of 1 and 8 covers seven complete slots, or $7 \times 15 = 105$ degrees; the sine of half of 105 or 52.5 degrees $= 0.79$, which means that when connected for six poles the coils have an effect of only 0.79, as against 0.938 when connected for eight poles. It is possible to avoid using the sine of half the angle and secure a factor which is sufficiently accurate practically by using the expression,

$$\sqrt{\frac{(\textit{Number of slots per pole})^2 - 2\,(\textit{Number of slots dropped})^2}{(\textit{Number of slots per pole})^2}}$$

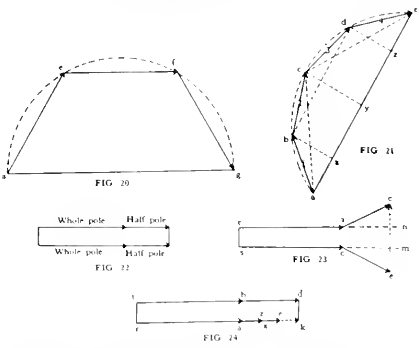
Using the same eight-pole example above, the number of slots per pole is $72 \div 8 = 9$ and the pole pitch is 1 and 10. When the coil is wound 1 and 8 it spans 7 slots and there are $9 - 7 = 2$ slots dropped. The expression then becomes

$$\sqrt{\frac{(9)^2 - 2\,(2^2)}{(9)^2}} = \sqrt{\frac{73}{81}} = 0.948$$

and similarly for the six-pole,

$$\sqrt{\frac{(12)^2 - 2\,(5^2)}{12^2}} = \sqrt{\frac{94}{144}} = 0.807$$

which agrees roughly with the other method. A coil should in no case be chorded more than half of the pole



FIGS. 20–24—VECTOR DIAGRAMS SHOWING THE E.M.F. RELATIONS IN THE PARALLEL PATHS OF THE CONNECTION SHOWN IN FIG. 19

pitch, as secondary disturbances of the magnetic field are occasioned by chording which become prohibitive at that point. The expression, "sine of half the angle spanned by the coil," is given the name "chord factor," and it should be considered in the work of reconnecting. For example, if the poles are changed from 8 to 6, as in the example above, and the chord factor changes from 0.938 to 0.79, the new line voltage should be $0.79 \div 0.938$ times the old, neglecting the effect of other changes which are being made. If nothing else was undergoing change and the normal voltage was 440 in the first place, it should be 370 after the change is made or, expressing it another way, if it was still operated at 440 volts after the change, the motor should be thought of as operating at about 18 percent over voltage.

The second general factor mentioned above is that of "phase insulation." It is the practice of many manufacturers to put heavier insulation on the coils at the ends of the polar groups which are mechanically adjacent to one another and which are also subjected to the voltage between phases, which may be the maximum voltage be-

*Two very good papers on this subject are found in the *Transactions of the A.I.E.E.*, Vol. XXVI, 1907, pp. 1485-1503, Messrs. Adams, Cabot and Irving, and Vol. XXVII, 1908, pp. 1077-1085, Jens Bache-Wiig.

tween supply lines. Such coils are illustrated at Nos. *3, 6, 9, 12, 15*, etc., in Fig. 1. By comparing this diagram with Fig. 9 for two-phase connection it appears at once that both the number and location of these so-called "phase coils" should be changed at the time the machine is reconnected from two to three-phase, or vice versa, assuming that the voltage can be changed so that a phase change is permissible. Also in changing the number of poles, the number and location of the phase coils must also be changed. In fact, whatever reconnection is attempted the phase coils should be checked and rearranged, since this is comparatively easy and adds considerably to the protection of the machine from breakdowns of insulation.

POSSIBLE RECONNECTIONS

The foregoing discussion of typical diagrams and general conditions leads up to the detailed consideration of the changes which are most frequently encountered in ordinary commercial service and the manner in which they can best be met. These changes in the order in which they most frequently occur are:—(a) Changes in phase and voltage of the supply circuit. These may occur singly or in combination; (b) change in frequency of the supply circuit; and (c) change in the number of poles of the motor. The (c) change may be independent of all other changes, because a faster or a slower speed is desired, or it may follow as a result of the (b) change in order to keep the same speed on the driven machine, when the motor is operated on the new frequency.

Changes in Voltage Only, all other conditions remaining the same. This is the simplest change which can be made in an induction motor winding and in principle is the same as that of a transformer coil in which the number of turns of wire in series must be varied in exact proportion to the voltage applied. Practically all commercial motors are arranged so that they can be connected for two voltages, say 110 and 220 or 220 and 440. This is accomplished by putting the polar groups in series, as in Figs. 3 and 10, for the higher voltage, and in parallel, as in Figs. 4 and 11, for the lower voltage. It is the writer's intention to cover the possibilities for most of the changes of this nature in Table I. For this reason it is essential that the working of this table be thoroughly understood. Suppose, for example, that the motor as it stands is connected for 2200 volts and is connected in series star as in Fig. 3. It is desired to reconnect it for 440 volts for the same horse-power, phase, cycles and speed. Four hundred and forty volts is 20 percent of 2200. Take Table I and use the horizontal column marked *3-Phase Series Star*. Since a reconnection is desired to give 20 percent of the original voltage read along the horizontal line till the figure *20* occurs. This is found first under the vertical column marked *3-Phase 5-Parallels*. This is of course obvious, because if the number of poles in the machine is divisible by 5 it could be reconnected in 5 parallels and operated on $2200 \div 5 = 440$ volts. But suppose the number of poles is not divisible by 5. Look still further along the horizontal line and the figure *19* appears under the vertical column headed *3-Phase 3-Parallel Delta*. In other words, if the number of poles in the machine is divisible by 3 it can be put in 3-parallel delta and operated on $\frac{2200}{3 \times 1.73} = 424$ volts, which is near enough to 440 to give perfectly satisfactory operation. If the number of poles on the machine is not divisible by 5 or by 3 it is evident from the table that it is not possible by any ordinary 3-phase connection to approach closer than 550 volts with a 4-parallel star connection, or 330 volts using a 4-parallel delta connection. The relation between 550 volts and 330 volts as just given is not quite the theoretical 1.73 which would be expected, but this is due to the table being made up to the nearest integral figure without using fractions. The error in this instance is three percent, which is immaterial. A little thought will show how the table is made up, and if greater accuracy is required a new table can be made up to any desired degree of exactness. An additional point which is brought out by the example just cited is that, so far as insulation is concerned, a motor may always be reconnected for a lower voltage—for instance, a 2200 volt motor may be reconnected for 440 volts—but, on the contrary, a motor originally designed for 440 volts may not be run on 2200, even if the reconnection is possible so far as number of turns is concerned, because the insulation will not stand the dielectric strain. It may be stated generally that practically all manufacturers use two classes of insulation up to 2500 volts, one class good up to 550 volts and the second good from 600 volts to 2500. This should be carefully considered and a motor never reconnected from the lower into the higher class, although the change from the higher to the lower is permissible from the insulation standpoint. It is hoped that Table I used in this manner may be helpful in answering questions in this class. These changes are practically all Class *A* changes when properly made.

Change of Phase Only—By far the commonest problem which presents itself in this class is the change from two to three-phase, and vice versa. Theoretically for the same voltage there should be about 25 percent more total turns in a two-phase winding than in a three-phase winding. Then, if a three-phase motor be reconnected for two-phase at the same voltage and with the same coils, it will exhibit all the symptoms of a motor operating at 25 percent over voltage and usually would overheat to a dangerous degree after a short period of operation. Conversely, a two-phase motor reconnected and run on three-phase at the same voltage with the same coils will show all the signs of a motor operating at 20 percent under voltage. Since in this case there are too many turns in the machine, one-fifth of the total coils might be dead-ended to secure the proper voltage on the remaining 80 percent. The dead coils should be distributed as symmetrically as possible around the machine to balance the voltage as nearly as possible on all phases. Parallels in the winding should be avoided, as they give a chance for unbalanced, circulating local currents,

which may cause excessive temperatures. Since the normal full-load current on a three-phase motor at any given voltage is about 12.5 percent greater than the two-phase full-load current at the same voltage, it follows that the three-phase horse-power will have to be cut down about 12.5 percent from the two-phase in order to keep the current density in the winding as it was on two-phase. Unless the current density is kept approximately the same greater heating will result. Another makeshift, shown in Fig. 13, is the so-called Scott or *T* connection for operating a two-phase motor on three-phase. By this scheme 14 percent of the coils in one phase of the two-phase machine are omitted as symmetrically as possible around the machine. One end, B_1 of this phase, is then connected to the middle of phase A_1—A_2. The resulting voltages between the points A_1—A_2—B_2 are practically in a balanced three-phase relation. This connection would give fairly good results if the coils between A_1 and B_1 were so situated on the machine that they would be acted upon by the magnetic field in exactly the same manner as the coils between B_1 and A_2. Practically, as motors are wound nowadays, this is rarely possible, and if the usual winding is connected in *T* there are practically always unbalanced currents in the three phases. The current in the high phase will be about 20 percent greater than the current in the low phase. This results in a poorer performance in torque, power-factor, efficiency and heating, as illustrated by the actual test data shown in Table II, which shows in three parallel columns the performance of a standard motor wound with normal two-phase coils, with two-phase coils connected in *T* and run on three-phase, and with normal three-phase coils. The efficiency on the *T* connection is 1.6 percent lower, the power-factor 5.2 percent lower, the starting torque 38 percent lower, the maximum torque 4 percent lower and the temperatures from 8 to 13.5 degrees higher than on the normal three-phase winding. This showing certainly puts this connection in the *c* class. The motor operates (if it can start the load), but it should not be considered where a large number of motors are concerned or where the cost of power is given any weight. This summary shows that changing from two-phase to three-phase, and vice versa, is at best very unsatisfactory, and the advice given in practically all cases of this nature is "Don't!" Better rewind with normal three-phase coils and avoid the host of troubles which follow in the train of an indifferently operating motor.

Of course, one essential in any phase reconnecting is to go over the winding and rearrange the "phase coils," or coils having heavier insulation, so that they will come properly at the ends of the groups where the voltage is highest. This is illustrated in Figs. 1 and 9.

One case of voltage and phase change which works out very well is the change from three-phase 550 volts to two-phase 440 volts, or vice versa. This uses all the turns in the winding for either connection, since the two-phase voltage should be about 80 percent of the three-phase, and since the higher voltage on the three-phase cuts down the current, which would otherwise be higher than the two-phase circuit. If the phase coils are rearranged there is practically no objection to such a reconnection and the motor will give essentially the same performance on either connection.

Table I shows the possibilities of these interphase connections, as well as the different voltage changes. For example, take the case just cited. Follow the horizontal line marked *2-Phase Series* to the first vertical column headed *3-Phase Series*. The figure is *125*. This means that a motor originally connected two-phase series, if reconnected three-phase series, should be operated on 125 percent of the original voltage. Or, if the two-phase voltage was 440 the three-phase would be $1.25 \times 440 = 550$ volts. The convenience of Table I is demonstrated for phase changes, as well as voltage changes, or for combinations of both.

Changes in Frequency—The occasion often arises for changing 25 cycle motors to 60 cycle and 60 to 25. There is also some changing done from 60 cycles to 50 and 50 to 60. Occasionally 40 cycle motors are changed to 60, but these changes are too infrequent to be of very general interest.

In all cases of changed frequency the question that first arises is:—How is the resulting change in speed to be taken care of? The synchronous speed of any motor (which is only a few percent higher than the full-load speed) is given by the general expression $\frac{\text{Alternations per Minute}}{\text{Number of Poles}}$. This would be $\frac{3000}{\text{Number of Poles}}$ for 25 cycles, $\frac{7200}{\text{Number of Poles}}$ for 60 cycles, etc. If then the frequency is changed and the number of poles left the same the resulting r.p.m. will vary directly as the frequency. This immediately brings up two questions:—First, is the mechanical design of the rotating part adequate to allow such a change in speed? Second, can the speed of the driven machine be adjusted to suit the new speed on the motor?

Consider first the case where the frequency is changed and the number of poles remain the same. The resulting change in speed in this case is taken care of either by applying the motor to a new load or by changing the pulleys on the old load so as to keep the same r.p.m. on the driven machine. The next thing that must be considered is the necessary change in the voltage applied to correspond to the change in frequency, or the other way about, if the new circuit at the new frequency has the same voltage as was used with the original frequency, how can the coils in the motor be reconnected so as to get the proper voltage on each coil?

The easiest rule to remember is to vary the applied voltage on the motor in exactly the same way as the frequency is varied. If this be done the magnetic field in the iron will remain the same and the current in the stator and rotor coils will remain the same, if the motor is working against the same torque. This is another way of saying that if the frequency and voltage are varied together, the motor will develop the same torque at all

times and have flowing in it approximately the same current. As noted in the earlier paragraphs, if the torque remains the same, the horse-power developed will vary directly as the applied frequency, that is, for example, a 60 cycle, 50 horse-power motor operated on 25 cycles at 41.6 percent of its original voltage would develop the same normal full-load torque, which would mean 20.8 horse-power.

The case most commonly met with, which is changing from 25 cycles to 60 cycles, can often be taken care of by impressing twice the voltage on the coils on 60 cycles as on 25 cycles, or in a concrete case operating a 220 volt, 25 cycle motor on 440 volts, 60 cycles, at about double the horse-power. Theoretically, this should be $60 \div 25 = 2.4$ times the voltage, instead of twice, and the resulting horse-power would be 2.4 times. However, 2.4 times is usually hard to get and two times comparatively easy. In this case suppose the motor was connected in series star for 440 volts on 25 cycles and it is desired to run it on 440 volts, 60 cycles. It should then be connected in parallel star and run on 440 volts, which would have the same effect as impressing 880 volts on the original series connection. On 60 cycles the motor would then run 2.4 times as fast and develop about twice the horse-power.*

Sixty cycle motors are often run on 50 cycles without change. From the rule above, that the voltage must vary with the frequency to keep the same magnetic densities, it will be noted that the densities on 50 cycles at the same voltage will be six-fifths of the 60 cycle densities. The motor will then operate as if it had 120 percent of normal voltage impressed. This will result in increased iron losses, which make the motor hotter, and the decreased speed on 50 cycles with same number of poles also make the ventilation poorer, so that the output of the motor in horse-power should be reduced to keep down the copper losses. This is logical in another way, because the horse-power at five-sixths speed should not be expected to be more than five-sixths of its full speed value. Another point that should be watched in changing frequency if the motor has a squirrel-cage rotor is that the rotor winding has enough resistance to give the proper starting torque. As the frequency is raised the resistance of the short circuiting rings at the ends of the rotor winding should be increased to keep the same relative value of starting torque to full-load torque. As long as the motor starts its load satisfactorily no change is necessary, but if trouble is experienced the short circuiting rings may have to be changed for ones of higher resistance. Conversely, when decreasing the frequency the resistance can be reduced to advantage, thereby cutting down the rotor copper loss and the heating.

Where the frequency is to be changed, but it is desired to keep the same speed, the number of poles must be changed in the same ratio as the frequency, or as nearly so as possible. For example, if a motor has four poles and is operated on 25 cycles it will have a synchronous speed of $3000 \div 4 = 750$ r.p.m. If the motor is to have the same speed on 60 cycles the nearest possible pole number is 10 and the synchronous speed will be $7200 \div 10 = 720$. It is apparent that in very few cases of this kind is it possible to reconnect the same winding. The main reason for this is in the throw or pitch of the coil. In the four-pole winding the individual coil spans approximate one-fourth of the stator bore, and in the ten-pole winding normal coils should, span about one-tenth of the stator bore. In the paragraph on chorded windings it was pointed out that the throw of the coil has an effect on the generated counter e.m.f. proportional to the sine of one-half the electrical angle spanned by the coil. This consideration makes hardly possible such a condition as connecting a winding for ten poles when the individual coils have a four-pole throw. When reducing the frequency the number of poles should become smaller to keep the same speed, and this introduces another difficulty in the magnetic circuit. In reconnecting the winding the object is to keep the total magnetic flux in the machine the same as it was originally. This keeps the magnetic density in the teeth constant. This total magnetic flux is divided up into as many equal parts or circuits as there are poles. The iron in the stator core between the bottoms of the slots and the outside of the core has to carry the flux for each magnetic circuit. Consequently, if there are ten poles and ten magnetic circuits the core iron below the slots has to carry at a given cross section one-tenth of the total magnetic flux. With the same total magnetic flux, if there are only four poles and four magnetic circuits, the same cross section of core has to carry one-fourth of the total magnetic flux, which it is probably unable to do. This is the reason why the rotor diameter and stator bore of a 25 cycle machine are smaller than those of a 60 cycle machine of the same horse-power and speed, although the outside diameter may be nearly the same. It is to get a larger cross section behind the slots for the passage of the magnetic flux, since the total flux is divided into fewer parts, owing to the smaller number of poles. From this it follows that a machine may in general be rewound or reconnected for a larger number of poles, but that great caution is required in reconnecting for a smaller number of poles. This leads up to the statement that it is easier to rewind or reconnect 25 cycle machines for 60 cycles than it is to reconnect 60 cycle machines for 25 cycles. This follows logically from the physical fact that there is more copper and more iron in 25 cycle machines for the same horse-power, voltage and r.p.m. than in 60 cycle machines. It is always easier to make changes where there is a larger supply of material available. Another condition that is against changing the number of poles on a squirrel-cage motor is the current in the short-circuiting rings of the rotor winding. These rings are in nearly the same case as regards current that the primary core is as regards magnetic flux. That is to say, the total secondary amperes, which remain nearly the same if the reconnection is done properly, are divided into as many circuits as there are poles.

*See articles by Mr. G. B. Werner in the JOURNAL, Vol. III, p. 400; and by Mr. R. E. Hellmund, Vol. III, p. 680.

and it follows at once that the smaller the number of poles the larger must be the cross-section of the short-circuiting rings, although the total secondary amperes remain nearly the same. Altogether, the possibility of reconnecting for different numbers of poles when changing frequency is usually a matter for the designing engineer to investigate.

Changes in the Number of Poles, all other conditions remaining the same. The need for such changes comes from the desire to speed up or slow down the driven machine to meet new requirements. It might be broadly stated that there are many cases where a change of two poles is permissible, as for example, changing from four poles to six, or from ten to eight and the like. The change would consist in rearranging the phase coils to agree with the new grouping and checking the chord factor, as mentioned above, to note its effect on the voltage. The proper diagram for the new speed can then be made up by comparison with the corresponding typical diagram in this article. It is often possible to get a fair operating half speed by connecting for twice the number of poles, as shown in Figs. 15, 17 and 18. Practically all reconnections involving pole changes are class *B* changes, in that they give only a fair operating performance.

The procedure in checking up a machine to see if it can be reconnected is first to ascertain the existing connection and the throw of the coils in order to know what the possibilities are in the way of number of turns and throw. Second, if it is a phase or voltage change, find directly from Table I what connections will give approximately the proper new voltage and new phase. If any one of these connections is possible with the number of poles in the machine, select it as the new connection and arrange the phase coils properly at the beginning or ending of the groups, or at each end of the groups if there are enough of them in the old winding. Since the speed has not changed the horse-power should remain approximately the same, and the current in the coils themselves will remain somewhere near the original. If the frequency is to be changed either independently or in conjunction with a phase or a voltage change, the applied voltage should be changed in the same direction and by the same amount as the frequency is changed, or if the voltage is to remain unchanged the number of turns in series in the coils should be changed in the opposite direction to the frequency and by the same amount. For example, if a 25 cycle motor is to be run on 30 cycles, it should have the voltage increased 20 percent, or else have the groups reconnected so that there will be 20 percent less turns in series and run on the same voltage.

If the number of poles is to be changed, and consequently the speed, check first the effect of the coil throw or chording with the new number of poles. Then think of the motor winding as generating counter e.m.f. and bear in mind that with a constant field a higher speed will generate more e.m.f. and a slower speed less e.m.f. Converted into voltage this means that with a higher speed a higher voltage should be applied in direct proportion and with a lower speed a lower voltage should be applied. If the voltage cannot be changed try to change the diagram of group connections so as to vary the number of turns in series in the right way, i. e., if voltage should be increased the same effect can be obtained by decreasing the number of turns a like amount. In all these cases it is the voltage per turn or per conductor which counts, just as in a transformer, and a careful consideration of the effect of different connections will show whether the desired change in voltage per conductor is being accomplished.

As a concrete example of the foregoing, assume a 25 horse-power, four-pole motor operating on 40 cycles, two-phase, 220 volts. It is desired to know whether it can be reconnected to operate on 60 cycles, three-phase, 550 volts at the same speed and horse-power.

An inspection of the machine shows that it has 72 slots and 72 coils and that any individual coil lies in slots 1 and 15, also that the groups are connected in parallel. Since there are $72 \div 4 = 18$ slots per pole, each slot is $180 \div 18 = 10$ electrical degrees and 14 slots = 140 electrical degrees. (The throw of 1 to 15 means spanning 14 slots). The sine of one-half of 140 degrees (or 70 degrees = 0.94 = chord factor, or figured by the formula without trigonometry, since there are 18 slots per pole and a throw of 1 to 15 means dropping 4 slots from exact pitch, the chord factor = $\sqrt{\dfrac{18^2 - 2 \times 4^2}{18^2}} = 0.948$. The synchronous speed of the motor on 40 cycles as it stands is $4800 \div 4 = 1200$ r.p.m. To get this same speed on 60 cycles it is evident the motor will have to be connected for $7200 \div 1200 = 6$ poles. If the throw of the coils be left 1-15 they will throw two slots further than full pitch, since $72 \div 6 = 12$ slots per pole and 1 to 13 would be exact pitch. Throwing the coil over pitch has the same effect as throwing it under pitch so the new chord factor on six poles $= \sqrt{\dfrac{12^2 - 2 \times 2^2}{12^2}} = 0.97$, or sine of one-half of 150 degrees = 0.98. Taking into account the changes in phase, poles, frequency and chording the new applied voltage per phase should be $\dfrac{880}{3} \times \dfrac{4}{6} \times \dfrac{60}{40} \times \dfrac{0.98}{0.94} = 305$ volts.

The explanation of this expression by terms is:— The first term, $880 \div 3$, comes from the change in phase from 2 to 3. Since the original connection was in parallel and was for two-phase, the voltage across one phase in series would be $2 \times 220 = 440$, and the voltage across both phases in series would be $2 \times 440 = 880$ volts. If the winding is divided into three separate phases not interconnected, the applied voltage on each phase would be $880 \div 3$. The next term, $4 \div 6$, is due to the change in poles. A motor with six poles would run slower on the same frequency than a motor with four poles and would generate less counter e.m.f. Consequently, the applied voltage should be decreased in the same proportion. This should not be confused

with the fact that the frequency is being changed in this case and the speed kept the same because a separate factor is introduced to take care of the frequency. The pole change should be considered as an item separate from the frequency change. The next term, 60 ÷ 40, is due to the change in frequency and is the application of the rule to change the applied voltage directly as the frequency is changed. The last term, 0.98 ÷ 0.94, is due to the difference in chord factor. With a throw of 1—15 the coils are more effective to generate counter e.m.f. on the six-pole than on the four-pole connection by the ratio of the chord factors 0.98 to 0.94, hence the applied voltage should be raised with the counter e.m.f.

As just stated, this figure of 305 volts means that if the winding was divided into three separate phases not interconnected in any way the voltage should be 305 volts across each phase. If the three phases are connected in star, as in Fig. 3, the applied voltage should be $1.73 \times 305 = 530$ volts. Since this is only about 3.5 percent off from the 550 volts which is to be used this motor will operate satisfactorily. This calculation for voltage so far neglects the difference in the so-called "distribution factor" between three-phase and two-phase, but this is immaterial. This factor acts the same way as the chord factor, and is about 0.955 for any normal three-phase windings and 0.905 for any normal two-phase winding, so that the applied voltage should really be $530 \times \frac{0.955}{0.905} = 560$ volts, which is almost exactly what is required. This motor could then have its phase coils rearranged for six poles and be connected series star and would be proper for the new conditions. The changes involved do not materially affect the slip, so that no change is required in the rotor winding. This example is not intended as an exact method of design, but simply illustrating a rough calculation to see what are the possibilities.

After a motor is reconnected or after any change is made in the winding, it should be started up slowly and the load gradually thrown on, observing carefully to see if there are any signs of distress, such as sudden heating, noise or mechanical vibration. If the motor seems to operate normally read the amperes in each phase and the voltage across each phase to see that they are balanced and are reasonable in amount. The full-load current for three-phase 550 volts is somewhere near one ampere per horse-power for normal motors of moderate speeds between 5 and 200 horse-power. At other voltages this will be inversely as the voltage e. g. at 440 volts, three-phase, about 1.25 amperes per horse-power. On two-phase the current per phase is about 87 percent of the corresponding three-phase value. If the readings as above look reasonable a thermometer should be placed on the stator iron and another on the stator coils and noted at 15 minute intervals for an hour, and at half-hour intervals thereafter, till the temperature is constant. The speed should be checked at intervals. If the r.p.m. show a tendency to decrease rapidly or fall below 90 percent of synchronous speed it may be suspected that the rotor has too much resistance and is getting hot. By making all these checks reasonable assurance may be had that the reconnection is satisfactory and damage to the machine avoided.

CONCLUSION

From the foregoing it can be seen that all changes, whether of phase, voltage, poles or frequency, may be considered as voltage changes and reduced to such terms. In making such calculations and comparing the results it is best not to apply a voltage that differs from the figured proper voltage by more than plus or minus ten percent. The general effect of high and low voltage may be expressed briefly, thus:—

High Voltage—

a—Increases magnetic density.
b—Increases magnetizing current.
c—Decreases "leakage current" (leakage reactive component).
d—Increases starting torque and maximum torque.
e—Decreases slip or change in speed from no load to full load.
f—Decreases secondary copper loss.
g—Increases iron loss.
h—Usually decreases power-factor.
i—May increase or decrease efficiency and heating, depending upon the proportions of primary copper loss and iron loss in the normal machine and also the degree of saturation in the iron.

Low Voltage—

a—Decreases magnetic density.
b—Decreases magnetizing current.
c—Increases leakage current.
d—Decreases starting and maximum torque.
e—Increases slip.
f—Increases secondary copper loss.
g—Decreases iron loss.
h—Usually increases power-factor.
i—May increase or decrease efficiency and heating, depending upon the proportions of primary copper loss and iron loss in the normal machine and also the degree of saturation in the iron.

Finally it may be stated that

1—Changes in voltage alone are the easiest class of changes and can usually be made.

2—Changes in number of phases alone can rarely be made satisfactorily and are usually only makeshifts.

3—Changes in number of poles are limited, due to the mechanical form of the coils.

4—Changes of frequency alone or in combination with voltage or phase can sometimes be made if changes in speed are not objectionable.

5—Complicated changes should not be attempted except by persons of some experience and should be handled with caution.

6—If the peripheral speed of the rotor (which equals rotor diameter in feet $\times$ 3.14 $\times$ r.p.m.) exceeds 7000 feet per minute on any proposed change the maker of the motor should be consulted before making the change.

7—In case of any doubt on any point refer to the manufacturer of the machine.

Effect of Exciting Current

ON THE ECONOMY OF OPERATION OF DISTRIBUTING TRANSFORMERS

E. G. Reed

THE EXCITING current of a transformer may be defined as the current flowing in the high-tension winding when no current is flowing in the low-tension circuit. It is not always appreciated that the exciting current causes a copper loss in the generating and primary distributing system, which is continuous as long as the transformer is connected to the distributing circuit. The following article gives an idea of the magnitude of the copper loss due to the no-load transformer current for a number of typical cases.

THE exciting current of a transformer is composed of two parts, one of which magnetizes the iron circuit and the other supplies the actual iron loss. The impressed voltage and magnetic flux are 90 degrees apart in time phase relation, since the magnetic flux in the iron circuit of the transformer is a maximum when the impressed voltage is zero, and zero when the impressed voltage is a maximum. As the magnetizing element of the exciting current is in phase with the flux, it also is at right angles to the impressed voltage and is, therefore, wattless. In other words, the magnetizing current represents energy which is used to magnetize the iron circuit. On the other hand, the eddy and hysteresis losses represent actual energy loss, which appears as heat in the magnetic circuit. The current which supplies this loss is in phase with the impressed voltage and is a working current. Fig. 1 shows the relation of these quantities. The total current on the primary side of the transformer from Fig. 1 is,—

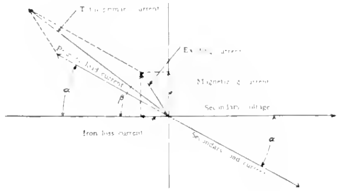


FIG. 1—VECTOR DIAGRAM OF LOAD AND EXCITING CURRENTS IN TRANSFORMER PRIMARY

$$I = \left\{ I_L^2 + m^2 I_L^2 - 2\, m\, I_L^2 \cos\left[180 - (\beta - \alpha) \right] \right\}^{\frac{1}{2}} \quad (1)$$

Where I_L is the primary load current due to the load current on the secondary side, and $m\, I_L$ is the exciting current. In this case m is the percent exciting current of the transformer, based on its normal full load current. The total line loss is equal to the square of the current multiplied by the total resistance on the primary side of the transformer, including that of the generator, distributing lines and other intervening apparatus, such as step-up or step-down transformers. The total distributing loss is, therefore,—

$$I_L^2 R + m^2 I_L^2 R + 2\, m\, I_L^2 R \cos(\beta - \alpha) \quad (2)$$

Where R is the total resistance on the primary side of the transformer as described above. The part of this loss due to the normal primary working current I_L is $I_L^2 R$ and the part due to the exciting current is $m\, I_L^2 R\, [m + 2 \cos(\beta - \alpha)]$. Since the exciting current is constant and independent of the transformer load, the loss due to it is also constant and independent of the load. Expressing $I_L^2 R$ as a percentage of the power P delivered, it may be written,—

$$pP = I_L^2 R \quad (3)$$

and the copper loss due to the exciting current is then,—

$$mpP\, [m + 2 \cos(\beta - \alpha)] \quad (4)$$

The total output P may represent the output of any number of transformers or of a single unit.

This, expressed as a percentage of the iron loss of the transformer, is,—

$$\frac{mp\, [m + 2 \cos(\beta - \alpha)]}{\textit{Percent iron loss of transformers}} \quad (5)$$

EXAMPLE

Let the following data refer to a group of transformers,—

Percent exciting current-m	=	5
Percent distributing copper loss-p	=	12
Percent iron loss of transformers	=	1
Power-factor of load	=	90

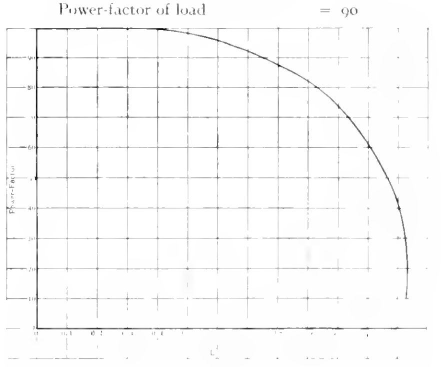


FIG. 2—LOSS IN TRANSMISSION LINE

Expressed in percent of the iron loss of the transformers, based on 12 percent distributing copper loss.

Therefore, $\alpha = 25^\circ\ 51'$.

$$\cos \beta = \frac{0.01}{0.05} = 0.2$$

Therefore $\beta = 78^\circ\ 28'$

Then $\cos(\beta - \alpha) = 0.607$

From equation (5) the loss now becomes,—

$$\frac{0.05 \times 0.12\, (0.05 + 2 \times 0.607)}{0.01} = 0.758$$

That is, the loss in the system due to the transformer exciting current is equal to practically 76 percent of that of the iron loss of the transformers. The curve in Fig. 2 shows this loss with loads of different power-factors. In this particular case it is interesting to note that the loss becomes a maximum when the load current and exciting currents are in phase, which occurs at a load whose power-factor is 20 percent. Of course the range of power-factor ordinarily encountered is from 100 to 80 percent. From the curve it is apparent that the loss increases rapidly with power-factors below 100 percent down to approximately 80 percent. Thereafter the loss increases more slowly with decrease of power-factor.

The Open Delta Connection for Transformers

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Westinghouse Electric & Mfg. Company

IT IS well known that two transformers may be connected in open delta to a three-phase system to deliver three-phase power. The characteristics of this connection may be understood by considering three transformers connected in closed delta and then noting the changes which occur when one of the transformers is disconnected.

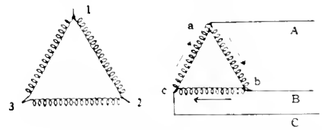


FIG. 1—DELTA CONNECTED BANK OF TRANSFORMERS

Such a bank is shown in Fig. 1, with high-tension delta *1-2-3*, low-tension delta *a-b-c*, and low-tension lines *aA*, *bB* and *cC*. The arrows indicate the positive direction of currents. The vector diagram, Fig. 2, shows the relation of the currents in the windings and lines. The currents in the three transformers are respectively i_{ab}, i_{bc}, and i_{ca}, 120 degrees apart. The current in the line *aA* is the vector sum of the currents flowing from *c* to *a* and from *b* to *a*; i.e.,—

$$I_{aA} = i_{ca} + i_{ba} = i_{ca} - i_{ab}$$

Similarly the line currents I_{bB} and I_{cC} are found as shown.

If the power-factor of the load be assumed as 100 percent, the voltages from *a* to *b*, *b* to *c*, and *c* to *a* will be respectively in phase with the currents i_{ab}, i_{bc}, and i_{ca}, as shown in Fig. 2. That is, the load carried by each transformer has the same power-factor as the load on the bank. It should be noted, however, that the line currents, I_{aA}, I_{bB}, and I_{cC} are not in phase with the voltages between lines E_{ab}, E_{bc}, and E_{ca}.

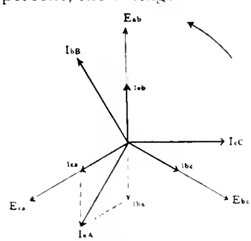


FIG. 2—VECTOR DIAGRAM OF DELTA CONNECTED BANK

Now suppose that the transformer *2-3-b-c* is removed, leaving the arrangement shown in Fig. 3. Since the load is unchanged, the line currents and voltages are the same as before, neglecting the effect of the regulation, which will be discussed later. Fig. 4 shows these line currents and voltages, which are the same as in Fig. 2. Now, however, all the current which flows out on the line *bB* must flow through the transformer winding *ab*, and consequently, if the load has a power-factor of 100 percent, the current and voltage in the transformer winding are 30 degrees apart, as shown in Fig. 4, and the transformer is, in effect, operating at 86.6 percent power-factor.

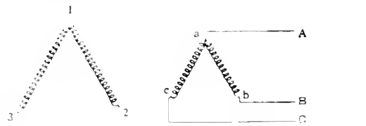


FIG. 3—OPEN DELTA CONNECTED BANK OF TRANSFORMERS

In the closed delta bank with a balanced load, the power of each transformer is $i_{ab}E_{ab}$ and the total power of the bank is,—

$$P = 3\, i_{ab}E_{ab}$$

$$\text{but } i_{ab} = \frac{I_{bB}}{\sqrt{3}}$$

$$\text{and therefore, } P = 3\,\frac{I_{bB}}{\sqrt{3}}\,E_{ab} = \sqrt{3}\, I_{bB}\, E_{ab}$$

which is the same as the total rating of the three transformers.

In the open delta bank, to deliver the same amount of power as before, the size of the transformers must be increased so as to carry the line current I_{bB}, and since there are now two transformers, their combined rating must be,—

$$\text{Total rating} = 2\, I_{bB}\, E_{ab}$$

This is about 15 percent greater than the total rating for the equivalent closed delta bank, but, as shown below, this is not necessarily a disadvantage.

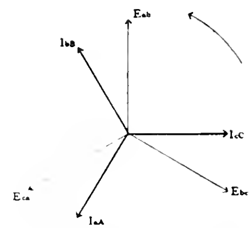


FIG. 4—VECTOR DIAGRAM OF OPEN DELTA CONNECTED BANK

REGULATION

The regulation for a closed delta bank carrying a load at 100 percent power-factor is shown in Fig. 5.

The no-load voltages are E_{ab}, E_{bc}, and E_{ca}, 120 degrees apart, and the drop in each transformer consists of a resistance component, ir, in phase with the current and a reactance component, ix, perpendicular to the current. These drops subtracted from the no-load voltages give the full load voltages E'_{ab}, E'_{bc}, and E'_{ca}.

The regulation for an open delta bank with a 100 percent power-factor load is shown in Fig. 6. The no-

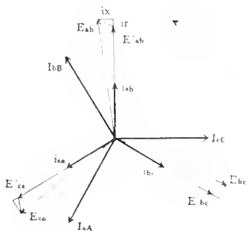


FIG. 5 REGULATION FOR CLOSED DELTA BANK

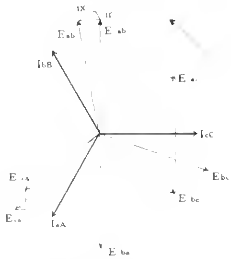


FIG. 6—REGULATION FOR OPEN DELTA BANK

load voltages are E_{ab}, E_{bc}, and E_{ca}, as before; the current I_{bB} flows in the line bB and in the transformer from a to b (Fig. 3), and the current I_{cC} flows in the line cC and in the transformer from a to c. The drop in the transformer ab consists of a resistance component, ir, in phase with the current I_{bB} and a reactance component, ix, perpendicular to I_{bB}, and this total drop, subtracted from the no-load voltage E_{ab}, gives the full-load voltage E'_{ab}. In the transformer ca, the resistance drop is in phase with the current I_{cC} and the reactance drop is perpendicular to this current, but the resultant drop must be added to the no-load voltage E_{ca} to give the full load voltage E'_{ca}, because the current I_{cC} flows through the transformer in a negative direction, i.e., opposite to the arrow Fig. 1, and opposite to the voltage E_{ca}. The full load voltage, E'_{bc}, is the vector sum of the voltages E'_{ba} and E'_{ac} and is found as indicated in Fig. 6. Thus there is an unbalancing in the

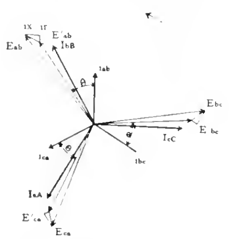


FIG. 7—VECTOR DIAGRAM OF DELTA BANK, CARRYING LOAD OF ANY POWER-FACTOR

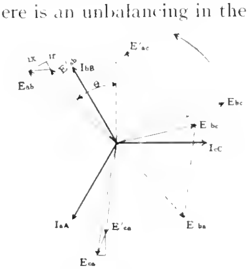


FIG. 8—VECTOR DIAGRAM OF OPEN DELTA BANK, CARRYING LOAD OF ANY POWER-FACTOR

full-load voltages of transformers connected in open delta. The unbalance, however, is small in amount and does not introduce practical difficulties.

For the sake of simplicity, the assumption has been made, thus far, that the power-factor of the load is 100 percent. By the same process of reasoning, however, the diagram may be constructed for any power-factor. Thus Fig. 7 is a diagram for three transformers in delta carrying a load of any power factor. Vectors i_{ab}, i_{bc}, and i_{ca} represent the currents in the windings of the three transformers and they lag behind the full-load voltages in the same windings by the angle θ, whose cosine is the power-factor of the load. The voltage drop in each transformer consists of the same triangle as before, Fig. 5, with the resistance component, ir, in phase with the current and the reactance component, ix, at right angles to the current. The vector sum of these two components, added to the full load voltages, gives the no-load voltages.

The corresponding diagram for two transformers in open delta is shown in Fig. 8. Since the power-factor of the load is the same as in Fig. 7, the angular relations of the line currents and the full-load voltages will be the same. The voltage drop in the transformer a-b is the same triangle as in Fig. 6, with ir in phase with the line current I_{bB} and ix perpendicular to I_{bB}. Likewise, the voltage drop in the transformer c-a consists of ir in phase with the current I_{cC} and ix perpendicular to I_{cC}; and the full load voltage E'_{bc} is the resultant of E'_{ba} and E'_{ac}.

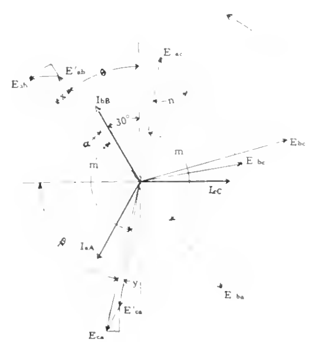


FIG. 9—PARTICULAR EXAMPLE OF GENERAL DIAGRAM SHOWN IN FIG. 8

It must be understood, of course, that the drops shown in these diagrams are very much magnified. In commercial transformers the resistance drop may be 0.5 to 2 percent of the voltage and the reactance drop, perhaps, 1 to 5 percent. The vector diagram is not adapted to the graphic solution of problems of this kind, where there is a large difference in the magnitude of the quantities considered, but it is valuable as a guide in working them out either by the symbolic or by the trigonometric method. An example will make this clear.

Example—Find the full-load voltages for the following case:

Given—

Two transformers connected in open delta.	
Transformer rating	5 k.v.a. each
Full-load output of the bank	8.66 k.v.a.
Resistance	1.06 percent
Reactance	2.325 percent
Power-factor of load	80 percent
No-load voltage	100 percent

Referring to Fig. 9, the full load voltage is drawn at an angle θ from the vertical such that $\cos\theta$ = the power-

factor of the load. The current I_{bB} is 30 degrees from the vertical. Therefore,

$$\alpha = \theta - 30^\circ$$

where α is the angle by which the current in the transformer lags behind the voltage.

Now the voltage drop in a transformer is,—

$$Drop^* = ir \cos \alpha + ix \sin \alpha + \frac{1}{200}(ix \cos \alpha - ir \sin \alpha)^2$$

From the trigonometric relations,—

$$\begin{aligned} \cos \theta &= 0.800 \\ \sin \theta &= 0.600 \\ \cos 30 &= 0.86603 \\ \sin 30 &= 0.50000 \end{aligned}$$

therefore,

$$\begin{aligned} \cos \alpha &= \cos \theta \cos 30 + \sin \theta \sin 30 \\ &= 0.800 \times .86603 + 0.6 \times 0.5 = 0.99282 \\ \sin \alpha &= \sin \theta \cos 30 - \cos \theta \sin 30 \\ &= 0.600 \times 0.86603 - 0.800 \times 0.500 = 0.11962 \end{aligned}$$

and the voltage drop in the transformer a-b is,—

$$Drop = 1.66 \times 0.99282 + 2.325 \times 0.11962 + \frac{(2.325 \times 0.99282 - 1.66 \times 0.11962)^2}{200} = 1.949.$$

Consequently the percent full-load voltage of the transformer, a-b, is,—

$$E'_{ab} = 100 - 1.949 = 98.05$$

The next step is to find the angle β between the voltage and current in the transformer ca. From the figure it is evident that,—

$$\beta = 120 + x + \theta - 90 = 30 + x + \theta.$$

Now the component of the drop in a-b which is perpendicular to the voltage, is (nearly)

$$\begin{aligned} & ix \cos \alpha - ir \sin \alpha \\ &= 2.325 \times 0.99282 - 1.66 \times 0.11962 = 2.1097 \end{aligned}$$

and therefore, $\sin x = \frac{2.1097}{100} = 0.0211$

Then,— $$\begin{aligned} \beta &= 68^\circ\ 5'\ 44'' \\ \cos \beta &= 0.37306 \\ \sin \beta &= 0.92780 \end{aligned}$$

and $$Drop = 1.66 \times 0.37306 + 2.325 \times 0.92780 + \frac{(2.325 \times 0.37306 - 1.66 \times 0.92780)^2}{200} = 2.779.$$

The percent full-load voltage of the transformer ca, then, is,

$$E'_{ca} = 100 - 2.779 = 97.221.$$

To find the full-load voltage E'_{bc} the angle between E'_{ab} and E'_{ca}, or m must be found. From the figure,

$$m = 120 + x + y.$$

The component of the drop in c-a which is perpendicular to E_{ca} is,

$$ir \sin \beta - ix \cos \beta = 0.6728$$

therefore, $\sin y = \frac{0.673}{100} = 0.00673$

$Sin\ x$ was found above, so adding the corresponding angles, we have,—

$$m = 121^\circ\ 35'\ 46''$$

and $$n = \tfrac{1}{2}(360 - 2m) = 58^\circ\ 24'\ 14.''$$

This gives us two sides and the included angle of a triangle, to find the third side, from which in percent,—

$$E'_{bc} = 95.28$$

*This equation is general if the angle of a lagging current be regarded as positive and the angle of a leading current as negative.

The foregoing solution may be somewhat simplified, and will give approximately correct results if the last term of the expression for voltage drop be disregarded. This gives,—

$$Drop = ir \cos \alpha + ix \sin \alpha$$

And the resulting full load voltages are,—

$$\begin{aligned} E'_{ab} &= 98.07 \\ E'_{ca} &= 97.21 \\ E'_{bc} &= 95.28 \end{aligned}$$

Table I shows the full-load voltages of these two transformers for loads of various power-factor.

TABLE I.—TWO 5 K.V.A. TRANSFORMERS IN OPEN DELTA

Resistance = 1.66 percent. Reactance = 2.325 percent.

	Percent No-Load Voltage	Percent Full-Load Voltage		
		100 Percent P-F	90 Percent P-F	80 Percent P-F
Eab	100	99.68	98.48	98.05
Ebc	100	97.09	95.63	95.26
Eca	100	97.36	97.15	97.23

Table II shows the full-load voltages for three of the above transformers in delta.

TABLE II.—THREE 5 K.V.A. TRANSFORMERS IN DELTA.

Resistance = 1.66 percent. Reactance = 2.325 percent.

Percent No-Load Voltage	Percent Full-load Voltage		
	100 Percent P-F	90 Percent P-F	80 Percent P-F
100	98.31	97.48	97.27

An emergency condition sometimes occurs due to an accident to one transformer of a closed delta bank, and the question arises, how much load the remaining two transformers will be able to carry in open delta. For the same heating, the same current should flow in the transformers as before; but, as the full line current now flows through each transformer, the line current must be reduced from its former value in the ratio

TABLE III.—THREE 3 K.V.A. TRANSFORMERS IN DELTA

Resistance = 1.99 percent Reactance = 1.56 percent.

Percent No-Load Voltage	Percent Full Load Voltage		
	100 Percent P-F	90 Percent P-F	80 Percent P-F
100	98.00	97.54	97.48

$$1 : \frac{1}{\sqrt{3}},$$

i. e., the two remaining transformers will carry 58 percent of the load of the original bank. An idea of the effect on the regulation may be had by comparing Tables I and II. The actual values in any particular case will of course, depend on the characteristics of the transformers involved.

Frequently it is desired to carry a load with two transformers instead of three. In this case transformers of sufficient size are installed and a comparison between the regulations of the open delta bank and the closed delta bank is less unfavorable to the open delta connec-

tion than the comparison above, because the larger transformers have, in general, better regulation than the smaller, especially at high power-factors.

Table III shows the full-load voltages of a closed delta bank of 3 k.v.a. transformers of the same type as the two 5 k.v.a. transformers considered in Table I. A comparison of these two tables gives an idea of the results of the two methods of connection for the same load.

Comparing the efficiencies of two V-connected trans-

TABLE IV—COMPARISON OF CLOSED DELTA WITH OPEN DELTA CONNECTION—DISTRIBUTING TRANSFORMERS

	Closed Delta Three 3 k.v.a.	Open Delta Two 5 k.v.a.
Capacity of bank—	9 k.v.a.	8.66 k.v.a.
Losses per k.v.a percent	100	88
Cost per k.v.a percent	100	97½
Weight per k.v.a percent	100	108

TABLE V—COMPARISON OF CLOSED DELTA WITH OPEN DELTA CONNECTION—POWER TRANSFORMERS

	Closed Delta 3-300 k.v.a.	Open Delta 2-500 k.v.a.
Capacity of bank—	900 k.v.a.	866 k.v.a.
Losses per k.v.a. percent	100	101
Cost per k.v.a. percent.	100	86.3
Weight per k.v.a. percent.	100	100

formers and three delta connected transformers for the same output, it is found that they are practically the same. Thus, the total loss in a bank of three 3 k.v.a. transformers of standard design is 291 watts at full load, or 32 watts per k.v.a. output; while in a bank of two 5 k.v.a. transformers the total loss is 248 watts, or 28.6 watts per k.v.a. of output. Similarly, in a bank of three 300 k.v.a. transformers the total loss amounts to 16.77 watts per k.v.a. output, while in a bank of two 500 k.v.a. transformers the total loss is 16.98 watts per k.v.a.

The total cost and weight are also nearly the same for the two schemes. Table IV shows a comparison of the losses, weights and costs for a bank of small distributing transformers, and Table V makes the same comparisons for a bank of power transformers.

One advantage of the open delta connection which may be important in some cases is that only two units are required instead of three. This means less floor space, and in the case of distributing transformers mounted on poles it means a neater and simpler arrangement.

SUMMARY

The foregoing points may be summarized as follows:—

1—The total transformer capacity required for an open delta bank to carry a given load is 15 percent greater than for a closed delta. This total capacity is in two units instead of three.

2—The voltage drop in the open delta bank is unsymmetrical, and this causes a slight unbalance in the three full-load voltages. This unbalance is negligible in most cases.

3—When one transformer of a closed delta bank is injured the two remaining transformers will carry 58 percent of the load with the same heating, but with a somewhat poorer regulation on two phases.

4—When transformers are chosen for a given load the above advantage of the closed delta connection partially disappears, on account of the larger size of the transformers for the open delta bank.

5—In efficiency and weight the open delta bank is approximately on a par with the closed delta, while in cost it shows a slight advantage.

6—The open delta connection involves two units instead of three, and requires less floor space than the closed delta arrangement.

The Engineering Evolution of Electrical Apparatus—XIX

THE HISTORY OF THE ARC LAMP—*(Cont.)*

F. Conrad and W. A. Darrah

WHILE engineers and manufacturers were bending their efforts to the perfection and improvement of the open arc lamp, there was one defect in all systems which was gradually making itself apparent and was destined later to cause the abandonment of the type. This was the short life which is now known to be due to the rapid oxidation of the hot carbons by the currents of air which continually passed over the arc. At the time that the open arc was being developed, however, the cause of the short life (usually about eight hours per set of carbons) was more or less a mystery, and it was accepted as a necessary condition which must be either tolerated or else minimized by increasing the length of the carbons.

There was also another growing force at work which eventually contributed in no small degree to the displacement of the open arc. This was the development of the incandescent lamp, which had established itself as a most desirable illuminant on constant potential circuits, and its advocates already had ambitious plans for sending the arc lamp to the scrap heap. These ambitions were doomed to fail, but their effect was twofold:—

1—They stimulated the advocates of arc lamps to strengthen their designs, to reduce their operating costs, and to raise their standards of service and illumination.

2—They developed the idea of excluding air from the light-giving element, thus preparing the way for the enclosed carbon lamp.

As a result of the engineering and economic forces at work the enclosed lamp was gradually evolved, marking a new era in arc lighting. The year 1893 may be fixed as roughly representing the advent of the new illuminant, although because of the gradual forces at work and the resultant rather large group of men who devoted their attention to it, it is very difficult to fix the exact date or any single inventor who may be said to be first. Many of the men who were active in this field are still at work today developing later lamps.

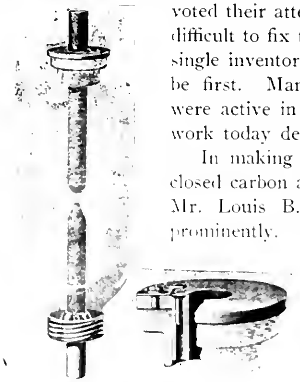


FIG. 29—EARLY MARK'S INNER GLOBE AND GAS CHECK FOR ENCLOSED CARBON ARC LAMP

In making a survey of the enclosed carbon arc field the name of Mr. Louis B. Marks stands out prominently. Marks and other investigators found that by placing a tightly fitting globe around the arc and causing the upper carbon to pass into the globe in such a manner that only a very limited amount of air could enter, as in Fig. 29, it was possible to multiply the life of a trim of carbons by ten or twelve, although the amount of light given out was somewhat decreased. This was a notable advance. The cost of trimming the lamp and renewing the carbons was reduced to at least one-tenth of its former value, while its efficiency was reduced by less than 50 percent. This was a handicap which the open arc could not withstand and, while it held its own for a considerable period, especially where already installed, it was now considered a superseded lamp. The five years which follow 1893 were marked by the appearance of the Wood, the Thomson, the Adams-Bagnall, Manhattan and Westinghouse enclosed carbon arc lamps.

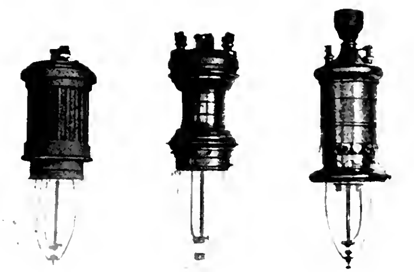


FIG. 30—TYPICAL EARLY ENCLOSED ARC LAMPS

The enclosed arc was naturally not hailed as a desirable invention by the carbon manufacturers, who held many anxious conferences at which the downfall of the carbon industry was freely foretold. Curiously enough, the actual result was almost the reverse. The number of lamps in use increased enormously; the coming of the enclosed arc reacted very favorably on the quality of the product, thereby warranting a higher price, and the result was prosperity for the carbon manufacturers. One immediate result of the improvement in the quality of the carbons was the general adoption of a mechanism in which the clutching device acted directly on the electrode instead of upon a steel rod. The direct effect was to shorten and simplify the lamp mechanism to a remarkable degree.

This type of a lamp, of course, was not without its failings. The arc lamp has always exerted a peculiar attraction for the small boy with a stone, and the operation of the lamp with a broken globe did not result in a long carbon life. There were also various troubles with clutches, cutouts, shunt coils and carbon holders which in the early days served to make the work of the designers interesting. One feature, namely, the "gas check" or economizer, has survived in the modern flame carbon arc lamp. The "gas check" consisted of a disc, usually of fireproof, insulating material so arranged that the carbon passed through its center with little clearance, thus preventing the entrance of air into the arc chamber. It was soon discovered, however, that if no

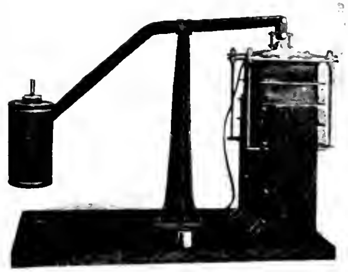


FIG. 31—ALTERNATING-CURRENT REGULATING REACTANCE

air was admitted the arc became unstable, and the ends of the electrodes hard, smooth and of very high resistance. Accordingly, means were devised for admitting air in limited quantities through spiral passages or similar expedients. The design of the globe in size, shape and distance from the arc was also a feature which required considerable careful attention before a commercial product was reached.

The Wood and Thomson lamps of this period were later taken over by the General Electric Company, while the plant of the Manhattan Construction Company passed into the hands of the Westinghouse Electric & Mfg. Company and formed the nucleus of its Newark works, the present arc lamp factory of that company.

Some time before the enclosed carbon arc lamp was commercialized, the introduction of alternating current into the United States was occupying the attention of the electrical world. About the time that the enclosed arc was well commercialized the alternating-current generating and distribution system had become firmly established, and it was only natural that an attempt should be made to utilize this for arc lamp operation.

The result was the invention of the "regulating reactance" and constant-current transformer, thereby starting a development which was eventually to send the constant-current arc generators to the scrap heap. The regulating reactance consisted chiefly of a coil in series with the arc circuit and a laminated iron core within the coil, provision being made to automatically change the relation of coil and core, thus varying the reactance of the coil. The coil was ordinarily moved and the core held stationary, the movement being arranged so that the varying inductance of the coil tended to maintain the current in the arc circuit constant. An early installation using the so-called tub transformer and alternating-current distribution system was made at Hartford, Connecticut. Because of historic importance this installation is interesting as an example of bold pioneer engineering. Among the earliest group of patents in the

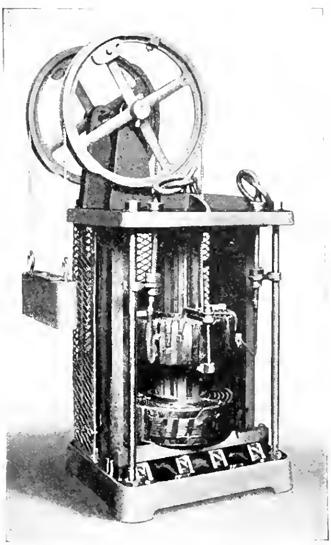


FIG. 32—CONSTANT CURRENT VENTILATED COIL REGULATOR

field were those of Mr. Malcomb H. Baker, about 1901, several of which formed the basis of more than one lawsuit in the commercial history of arc lighting. Fig. 31 shows the essentials of the scheme as it was then developed.

The regulating reactance was soon followed by the constant-current transformer, which ultimately very largely displaced it. The constant-current transformer was a natural development from the regulating reactance and, together with the alternating-current enclosed carbon lamp, constituted a system which for convenience, simplicity and maintenance was a marked advance. The regulating transformer as usually constructed consisted of two coils, one stationary and one movable, the movable coil being counterbalanced and adjusted to approach or recede from the fixed coil with a minimum of friction. The primary coil was usually stationary, while the secondary was repelled from the primary in proportion to the current passing through the secondary; however, as the secondary coil was repelled, the magnetic flux through the secondary decreased, and the induced current and voltage were accordingly diminished. The result was to keep the current constant. Refinements of design naturally followed in the development of a type of apparatus which today is one of the most satisfactory sources of constant current for arc lamps. The latest type with ventilated coils, together with the flame carbon arc lamp, comprises the present system. A glance at the simplicity of this device, Fig. 32, consisting of two coils about an iron core, will readily explain why the older constant-current generator with its coil troubles, commutator troubles, rotating parts and complicated regulating mechanism could not survive. The inherent defect in the system, however, was the low efficiency of the enclosed carbon lamp operating on alternating-current circuits, which had the inevitable effect of causing it to be finally discarded in favor of newer types.

The mechanisms of the various types of enclosed arc lamps had by this time become more or less standardized, so that all were the same in essential principles. Some form of clutch acting directly on the carbon itself was standard in all makes. For series circuits, both direct and alternating current, differentially acting series and shunt coils, a means of adjusting for different arc lengths, an automatic cutout actuated by excess voltage over the shunt coil, a starting resistance which was normally short-circuited by the automatic cutout, and a hand-operated switch which served to completely short-circuit the lamp as a protection to trimmers when working on live circuits, were features of practically all makes, the only differences being the relative location of the parts. An alternating-current series lamp mechanisms which is typical of all series mechanisms is shown in Fig. 33, and the general appearance of the essentially similar direct-current mechanism is shown in Fig. 34.

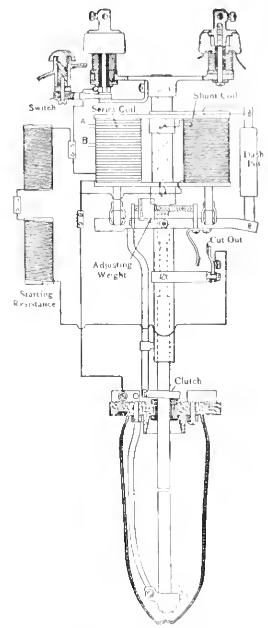


FIG. 33—CIRCUIT DIAGRAM OF AN ALTERNATING-CURRENT SERIES ENCLOSED ARC LAMP

The enclosed arc lamp, by reason of its freedom from fumes, more quiet operation and also because of its small power consumption and smaller intrinsic bril-

liancy, was much more suited to indoor illumination than had been its predecessor, the open arc lamp. The rapid increase in constant potential mains for incandescent lamp and motor use was also favorable to the use of the enclosed arc lamp indoors. The mechanism for constant potential circuits was much simpler than for series circuits, including only a series coil, together with a ballasting resistance for direct-current circuits or a reactance for alternating-current circuits. A typical 250 volt direct-current constant potential enclosed arc lamp is shown in Fig. 35, and a similar type of 110 volt alternating-current lamp is shown in Fig. 36. Where two or more lamps were to be operated in series-multiple on constant potential circuits a differential mechanism was required very similar to that of the constant-current lamps, and a resistance was included which was cut into the circuit in place of the arc lamp by the automatic cutout if the carbons in any one lamp burned out or the mechanism failed to operate.

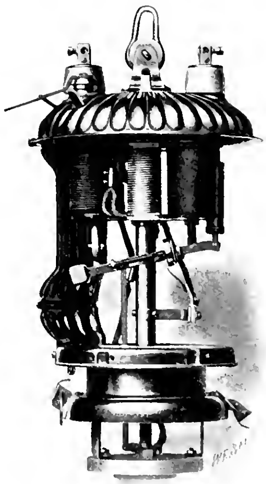


FIG. 34—DIRECT-CURRENT SERIES LAMP MECHANISM

Even before the enclosed carbon arc lamp had reached its widest application a number of inventors had devised the light unit which was to be one of its successors. Early in 1902 Mr. C. P. Steinmetz experimented on a magnetite electrode, while in 1903 Mr. W. R. Whitney developed a lamp with one consumable electrode composed of the oxides of iron, titanium and chromium, while the other electrode was called non-consumable and consisted of a copper block. The electrodes had a remarkably long life for lamps of that period, because the lower or negative electrode which supplied the arc stream with the luminous materials was composed of oxides and, therefore, was not affected by the air, while the upper or positive electrode consisted of a block of copper of such size that radiation maintained the temperature low enough to prevent oxidation.

The efficiency of the new lamp was high compared with the preceding lamps. The original claims for electrode life were 500 to 600 hours, but practical consideration soon reduced these to about 60-75 hours. The General Electric Company commercialized this type of illuminant. The early lamp was subject to numerous difficulties, however. In spite of all that could be done the electrodes would become covered with an insulating slag, or a fine red powder (iron oxide), which was a good insulator. The electrode material would melt and fall on the globe, breaking it. Windstorms would blow the fumes from the electrodes down the chimney, causing them to collect on the globe, after which the amount of light that escaped barely equaled that from an enclosed carbon arc.

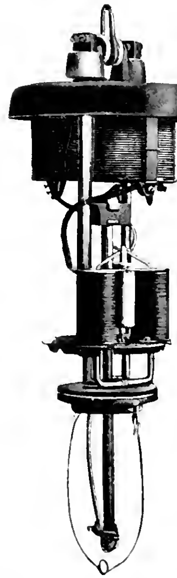


FIG. 35—250 VOLT CONSTANT-POTENTIAL DIRECT-CURRENT ARC LAMP MECHANISM

With resistor for ballast and for series-multiple operation.

Hardly had the early lamp been placed upon the market when the Westinghouse Company produced a lamp using iron, titanium and chromium oxides, but so radically different in principle that many of the earlier defects were either eliminated or greatly reduced. This was the so-called metallic flame lamp. In this lamp the

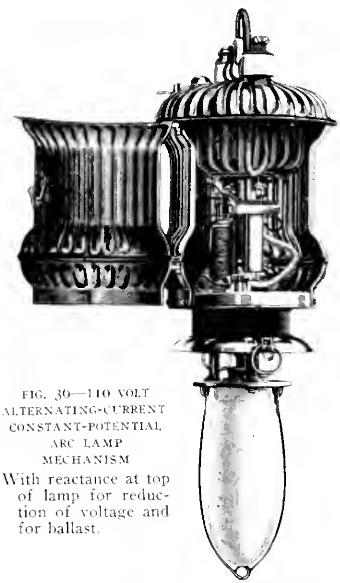
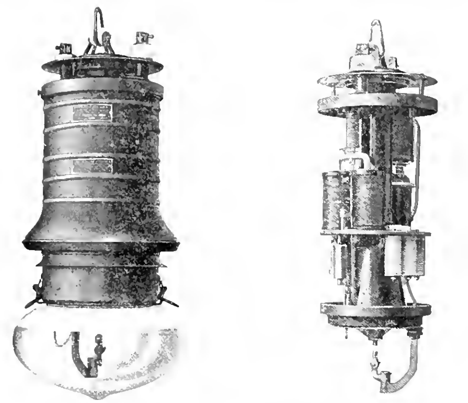


FIG. 36—110 VOLT ALTERNATING-CURRENT CONSTANT-POTENTIAL ARC LAMP MECHANISM

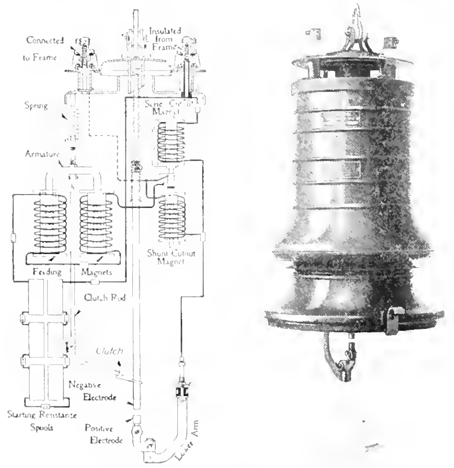
With reactance at top of lamp for reduction of voltage and for ballast.

negative or oxide electrode, which must necessarily be long, was placed uppermost, while the small positive electrode below consisted of a double spiral tightly wound from copper and steel ribbons. One of the essential features of this lamp is the "down draft." In all previous arc lamps the air heated by the arc had passed directly upward and out of the lamp. This was well



FIGS. 37 and 38—METALLIC FLAME SERIES ARC LAMP
With and without case and globe.

enough in the carbon lamps, and in the early magnetite lamp it was not prohibitive, although it caused the rapid accumulation of soot upon the cooler upper electrode. However, by causing the heated gases in passing upward to draw new air downward around the arc, it was found



FIGS. 39 and 40—CIRCUIT DIAGRAM AND EXTERNAL VIEW OF METALLIC FLAME SERIES ARC LAMP

possible to overcome a large part of the slag and soot difficulties and to mount the negative electrode uppermost, thus materially improving the natural distribution of the light and the efficiency. Lamps of this type are shown in Figs. 37 to 40, inclusive.

The development of this type of lamp by both companies was naturally rapid, the soot-forming and light-giving characteristics being materially improved, most of the improvements being in the nature of a better mechanical structure and an increase of the margins and factors of safety, the basic principles remaining unchanged. The electrodes of these lamps have a life of about 250 hours, while the energy consumption is about 0.4 watt per candle.

Owing to the rectifying characteristics of any metallic flame arc, it is impossible to operate it on alter-

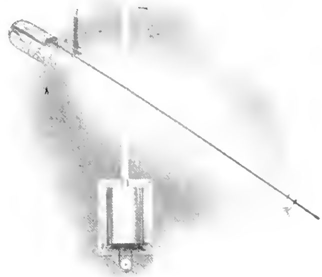


FIG. 41—EARLY COOPER-HEWITT MERCURY VAPOR ARC LAMP

nating current at less than about 500 volts; hence its practical operation on alternating current is impossible. The early lamps, therefore, were operated on direct-current generators similar to those used with the old open arcs. For a time it looked as if it would be impossible to take advantage of both the simplicity of the constant-current transformer and the high efficiency of the metallic flame lamp. One necessary link was missing, which was to be supplied in the course of the development of the mercury rectifier.

In 1860, Way discovered that if an electric circuit was opened by a mercury contact a long, brilliant green

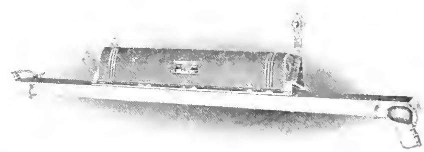


FIG. 42—MERCURY VAPOR ARC LAMP WITH AUTOTRANSFORMER FOR OPERATING ON ALTERNATING CURRENT

arc was produced. Beyond the announcement of the discovery in scientific journals little further progress made at the time, and Way's discovery lay dormant for nearly forty years. There were many causes for this. Existing arc lamps met existing needs, and there was no obvious commercial method of utilizing mercury, which was then a very expensive metal, readily oxidized by an arc in air. About thirty-five years later Dr. Peter Cooper Hewitt began experimenting with the mercury arc, but instead of attempting to maintain the arc in air he soon tried to remove the air, thus overcoming many of the difficulties which had proved unsurmountable in the past. The result was a long, bright, stable arc, with a rather high efficiency and a long life. One of the early

lamps is shown in Fig. 41. The Cooper Hewitt mercury vapor lamp was commercialized about 1901 in the form of a long glass tube about one inch in diameter, with an electrode in each end. The lower end of the tube contained a quantity of mercury and was usually made the cathode. To start the lamp it was necessary to tilt it sufficiently for the mercury to bridge the space between

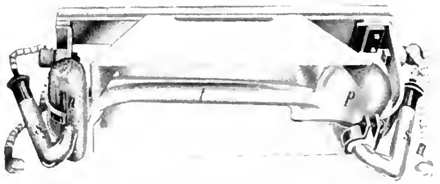


FIG. 43—TYPICAL QUARTZ TUBE BURNER FOR MERCURY VAPOR ARC LAMPS

the electrodes, when it would be immediately vaporized and the arc established. The early lamps were started by tilting with the hand. Requirements soon became more rigid and various automatic starting devices were developed, the most satisfactory consisting of an electromagnetic arrangement to raise an end of the lamp when current was applied.

The Cooper Hewitt glass mercury vapor lamps may be classed as a step in advance equal to that taken by the introduction of the metallic flame lamp. The light, being approximately monochromatic and well diffused, is excellent for continuous, accurate work. The life of the lamp is long and the attention required small. The light from the mercury arc is of such a nature that all shades of red appear black and other color values are distorted, with the result that any objects which depend upon color for their distinguishing feature have a peculiar appearance in this light. Where red rays are desirable, a light transformer or polarizing reflector may be placed behind the tube.

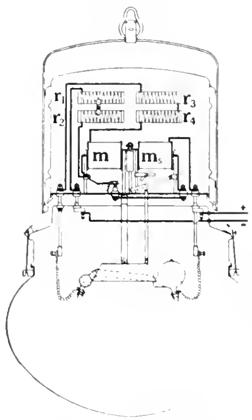


FIG. 44—DIAGRAM OF 220 VOLT, 3.3 AMPERE, QUARTZ TUBE MERCURY VAPOR ARC LAMP

The efficiency of the original lamp was less than that of later commercial units. These facts have led to efforts to improve the efficiency and color by the introduction of other compounds and by operating the arc at a higher temperature. Up to the present the former method has entirely failed of commercial application, while the latter has succeeded, due to the timely discovery of the art of making and working transparent quartz in the oxyhydrogen flames. As a result, in about 1912, there was placed upon the market the Heraus quartz tube mercury lamp, which differs from its predecessor mainly in the higher temperature and pressure at which the arc is operated, thus securing a light much richer in red rays and a materially higher efficiency, together with a remarkable reduction in the size and compactness of the resulting unit.

FIG. 54 CONSTANT CURRENT RECTIFIER BULB

For supplying current to 50 arc lamps and capable of delivering seven amperes at 4000 volts

All metallic vapor arcs are rectifying to a certain extent; that is, when the arc is established it will pass current in one direction, but it is impossible to reverse the current except on application of a considerabel voltage, whose value depends upon the metal. This value is very high in the mercury arc, and hence the mercury arc forms an ideal rectifying apparatus. A consideration of these facts lead Dr. Cooper Hewitt to the consideration that since this apparatus would allow current to pass in one direction only, it might be employed as a "rectifier" or a device to convert or rectify alternating current into direct current. Such was the start of the present mercury arc rectifier which was almost immediately adopted for the production of constant direct current for arc lighting circuits in connection with the constant-current transformer, already available. Thus the last link of

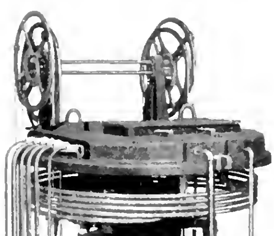


FIG. 40—75 LIGHT MERCURY VAPOR RECTIFIER CONSTANT-CURRENT REGULATING TRANSFORMER WITH SWITCHING PANEL

the chain was completed and the present metallic flame arc system was commercialized, omitting the troublesome direct-current generator and the inefficient alternating-current enclosed carbon arc lamp.

(To be continued)

Reversing a Three-Phase Motor

C. W. Kincaid

To understand why interchanging two leads of a three-phase induction motor will cause it to rotate in the opposite direction it is first necessary to know what causes the magnetic field in the motor to rotate. A three-phase machine usually has three winding groups per pole (one for each phase), and the groups are connected as shown in Fig. 1 for a two-pole machine and in a similar manner for larger number of poles. From this diagram, it will be seen that if the current enters by two leads and goes out the other lead, the direction of currents in the different groups will arrange themselves in groups of three which have the current in them in the same direction. Also, the middle group of the three will be the phase wh'ch has the current going out (i. e., from the star point to the lead). The arrows show one instant when the currents are flowing toward the star point in phases *A* and *C* and flowing away from the star point in phase *B*.

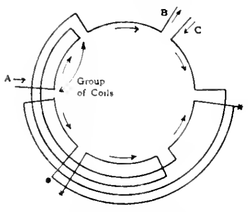


FIG. 1—SCHEMATIC DIAGRAM OF POLE GROUPS FOR A TWO-POLE, THREE-PHASE MOTOR

The instantaneous values of current in a three-phase circuit are shown in Fig. 2, plotted with respect to time. At the instant marked *1*, the *B* phase is at a maximum and phases *A* and *C* are at one-half value and in the opposite direction from phase *B*. At the instant marked *2*, the *B* phase has decreased to 86 percent of its maximum value. If the field produced by these currents in the windings of Fig. 1 is plotted at the two instants the movement of the field and its direction may be seen.

A section through the machine at right angles to the shaft is shown in Fig. 3, the groups of coils in each phase being marked *A*, *B*, *C*, etc., for a two-pole machine. Groups A_1 in the upper layer, or top coils, are connected in the rear by the diamond part of the coils to A_1 in the lower layer or the coils in the bottom of the slots. Coils A_1 and A_2, acting in the same direction, produce the field marked *A* in Fig. 4. In Fig. 2, position *1*, the current in phase *B* was twice as great as *A*, and therefore will produce the field marked *B*, which has a maximum twice that of *A*. The current in phase *C* is the same as *A*, and therefore will produce field *C*. When these are added, they will produce the resultant field shown by the dotted line, which has its center just between phase groups C_1 and A_2.

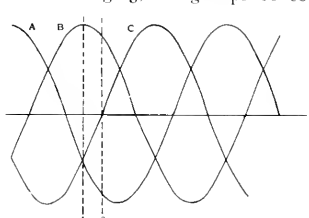
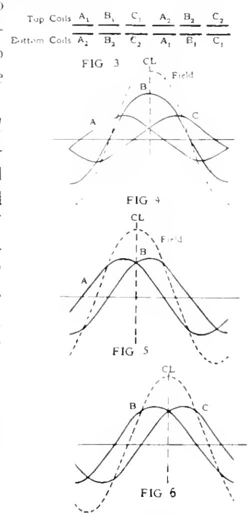


FIG. 2—CURRENT WAVES OF A THREE-PHASE CIRCUIT

In Fig. 5, the same thing has been done as in Fig. 4, except the current values have been taken as shown for position *2*, Fig. 2, i. e., phase *A* is 86 percent of maximum value, phase *B* is 86 percent of maximum value and phase *C* is zero. In this case the center line of the resultant field has moved to the left and is in the center of group C_1. By taking other positions in Fig. 3 and drawing figures similar to Figs. 4 and 5, the resultant field will be shown to continue to move to the left.

Now reverse leads *A* and *C* and see which direction the resultant field will move. In position *1*, *A* and *C* have the same value of current and in the same direction and, since phase *B* has not been changed, the same conditions will exist as in Fig. 4 and the center of the resultant field will be between C_1 and A_2. A diagram is shown in Fig. 6, corresponding to position *2*, Fig. 2, having the current that was in phase *A* in the phase *C* conductors and, since phase *C* is at zero, the *A* conductors are idle. This combination has a resultant field as shown with its center line moved to the right from Fig. 4 and on the center of phase group A_2. Further positions on Fig. 2 will cause this field to move to the right continuously. Plotting the field produced by reversing any two leads will make the resultant field move toward the right, the same as shown by reversing leads *A* and *C*, since the conditions as shown occur once every cycle.



FIGS. 3, 4, 5 and 6—DEVELOPMENT OF POLE GROUPS AND CORRESPONDING FIELD FORMS AT SUCCESSIVE TIME INTERVALS

Since reversing two leads on a three-phase motor has made the field rotate in opposite directions and the armature tries to follow this rotation, the direction of rotation of a three-phase induction motor or synchronizing motor will be reversed if any two leads are interchanged in their connection to the supplied power.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

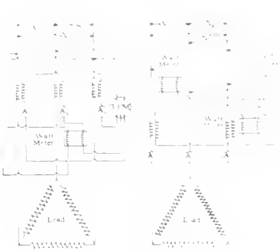
1269—Measuring Mechanical Output of Synchronous Motor—A synchronous motor is used both for supplying mechanical power and for power-factor correction. How can I measure this mechanical power output?

S. S. V. (NEW JERSEY)

The mechanical output of a synchronous motor is the product of the electrical power input and the motor efficiency at the given load and power-factor. The electrical power input may be measured by means of a wattmeter, but the efficiency must be calculated from data obtained from tests on the machine. The manufacturer of the motor will probably be able to furnish this efficiency data. However, if the motor is of reasonably large size, say above 200 k.v.a., and is operating at a power-factor of 70 percent or higher, an efficiency of 0.90 may be assumed. Then (kilowatts output) = (kilowatts input) × 0.90, or (horse-power output) = (kilowatts input) × 0.90 × 1.34. Q. G.

1270—Testing Power-Factor Meter—Please discuss methods of checking power-factor meters. H. J. A. (N. Y.)

Single-phase power-factor meters may be checked by means of a voltmeter, ammeter and wattmeter. A polyphase three-wire circuit will be found convenient, since both leading and lagging power-factor may be obtained by arranging the loads in the two phases. If only a single-phase circuit is available a check on lagging current may be made



FIGS. 1270 (a) and (b)

by means of a choke coil or some other form of reactance. The calculations, of course, are simple, since *power-factor* = $\frac{watts}{volts \times amperes}$. The meters necessary to check a two-phase power-factor meter are a polyphase wattmeter (or two single-phase meters), two ammeters and two voltmeters. The formula is *power-factor* = $\frac{\text{sum of wattmeter readings}}{\text{sum of volt-amperes in the two phases}}$.

Three-phase meters of the three-current type construction, such as the three-phase switchboard type, may be checked with a single wattmeter when connected as indicated in Fig. 1270(a). In this case a balanced three-phase load is necessary. Simultaneous readings must be taken on all meters. The voltmeter readings should agree with each other, and likewise the readings of the ammeters. In this connection $\sin\theta = \frac{W}{EI}$, in which W = wattmeter reading, E = voltmeter reading, I = ammeter reading and θ = the phase angle. The cosine or power-factor may then be found by referring to a table of natural functions of angles. If it is found impossible to maintain a balanced load, a three-phase meter may be checked by the two-wattmeter method, the connections for which are given in Fig. 1270(b). The power-factor can be calculated by using the sum of the wattmeter readings and the average of the voltmeter and ammeter readings and substituting in the formula

$$W = \sqrt{3}\,E\,I\cos\theta, \text{ or } \cos\theta = \frac{W}{\sqrt{3}\,E\,I}$$

(power-factor). This method is only approximately correct on unbalanced loads. The power-factor may also be determined from the ratio of the wattmeter readings with the connections given in Fig. 1270(b). In this case a balanced load is necessary and the formula used in calculating power-factor is,

$$\cos\theta = \frac{1}{\sqrt{1 + 3\left(\frac{1 - N}{1 + N}\right)^2}}, \text{ in which}$$

N is the ratio of the wattmeter readings, obtained by dividing the smaller reading by the larger. In testing power-factor meters the best results can be obtained when voltages and current are kept normal. O. B. R.

1271—Size of Engine—Size of engine being given, how is size of generator to be direct connected to it determined? P. J. (OHIO)

For a direct-current generator, 0.746 × engine brake horse-power equals the equivalent kilowatt capacity of the engine, which will be the power input to the generator. Multiplying this quantity by the assumed efficiency of the generator gives the kilowatts output of the generator. The efficiency may be assumed to be 90 percent, which is an average value. Thus 0.90 × 0.746 × Br. Hp = the kilowatt rating of the generator. In the case of an alternating-current generator the rating as found above must be divided by the power-factor at which the generator is to be rated to determine the k.v.a. rating. The above is based upon the assumption that brake horse-power is known. In case it is not known it may be found by multiplying the indicated horse-power by the engine efficiency, an average value of which is taken as 0.90. The generator which is selected should have the same approximate overload capacity as the engine. Q. G.

1272—Direct-Current Transmission—Assuming two industrial plants located 2000 feet apart, each with its own light and power plant. Conditions make it necessary to concentrate all the generating equipment at one plant and supply the necessary 250 kw to the distant plant over a pole line. Three-wire direct-current 125-250 volt generators are used at both plants, and both are equipped with 230 and 220 volt motors. It is proposed to group all the 230 volt motors at the generating end, and to group all the 220 volt motors at the distant plant. Then maintain 235 volts at the generator and allow ten volts drop in the line, so that 225 volts would be available at the distant plant. This would also allow five volts drop between the mains and motors at both ends. Aside from the heavy cost for copper, what other objections are there to this arrangement? What would be a more practical arrangement?

P. J. (OHIO)

The method mentioned would involve heavy cost for copper, as noted. As an alternative to this arrangement we would suggest the installation of boosters in the generating station, arranged to take care of from 15 to 25 percent drop in the transmission. The arrangement of the booster equipment would depend on the method of obtaining the neutral conductor in the distant plant. Without information as to the extent of the lighting load, it is impossible to determine whether it will be more economical to carry the third conductor from the generating plant or to install a balancer set at the distant industrial plant. In case the third conductor is carried from the generating plant, a booster must be provided in both sides of the circuit. This, in the case of a motor-driven outfit, would require a three-machine set. Where the balancer set is located in the distant plant, a single booster would be satisfactory. The method of drive used with either outfit will depend on local conditions, as it may be possible to belt or direct connect the boosters to the main generating unit. F. C. H.

1273—Solvent for Bakelite—Is there any solvent that could be used to facilitate stripping an armature winding that had been impregnated with bakelite? P. J. (OHIO)

There is no solvent for bakelite in its final stage. Sometimes, however, windings can be removed by boiling in a concentrated solution of lye and water. Usually armature windings have to be totally destroyed in stripping. In some types of machines, if a bakelized armature is short-circuited, it is cheaper to scrap the armature than to attempt to repair it. L. T. F.

FINANCIAL SECTION

With the present issue, a financial section is included. It is planned to make this section of the JOURNAL *a regular feature in the future. A prominent Wall Street financial writer has been secured as financial editor. Discussions of an educational nature will be given regarding public utility financial matters, along with other items of value to electrical men generally.*

ELECTRICAL SECURITIES

More and more the conservative investor is turning towards the securities of companies, the stocks and bonds of which are based on the generation and utilization of electricity for light, power and transportation. Aside from securities of street railway companies, the standard investment securities for many years have been those of steam railways, industrial corporations (to use the word "industrial" in the sense in which it is generally used in speaking of investments), government, state and municipal bonds, but now the stocks and bonds of electric light and power companies are beginning to receive that attention which they have long deserved, and it is to them that many conservative investors are turning for the investment of a considerable part of their funds.

Electric railway securities for a time were quite popular with many investors, but the demand for the best possible service with the lowest possible rate of fare, the exactions of labor, the heavy burdens placed on the companies by municipalities and the rise of the jitney, combined to cause a depression in these securities, which as yet, even with the rapid passing of the jitney, they have not been able to overcome. Eventually street railway securities may come back to their own, but at present it is the stocks and bonds of electric light and power companies which are attracting more and more the attention of the investor who is looking for security of investment, stability of earning power and future enhancement in the market value of his holdings.

While men directly connected with the light and power industry are, of course, entirely familiar with the wonderful growth of the industry in a physical and mechanical sense, the majority of them probably has paid small attention to what their work has done for the investor in light and power securities, these practical workers having been too busily occupied in extending the service field of the light and power industry to take note of the steadily increasing intrinsic value of the securities brought about by the work which they were performing so well.

The growth of the light and power industry has been one of the industrial and financial wonders of the United States. In 1914 it is estimated that the total revenue of the electrical industry of the country was in excess of \$2 265 000 000. Of this, electric manufacturing furnished \$450 000 000; electric railways, \$730 000 000; electric light and power companies, \$400 000 000; telephone companies, \$350 000 000; telegraph companies, \$85 000 000; private or isolated lighting and power companies, \$125 000 000, and

FINANCIAL SECTION

miscellaneous lines of electrical industry, \$125 000 000. It is the electric light and power branch of the industry, however, which is making the most rapid strides in both earnings and service. In 1902 the total revenue of the light and power companies of the country was but \$78 735 500, while in 1912 this had increased 254.2 percent to \$278 896 000, and for 1915, despite the general business depression of the greater part of the year due to the European war, it is estimated that it will be well over the \$400 000 000 mark set by 1914.

From 1902 to 1912 capacity of generating plants increased 313.6 percent, output in kilowatt-hours increased 375.8 percent, expenditures for construction increased 334.8 percent, and the funded debts of the companies increased 252.7 percent. Since 1912 no exact figures are available, the Census Bureau making its reports only for the five-year periods, but the growth of the industry since that year has been no less remarkable than in the years preceding.

Almost \$2 500 000 000 of securities of electric light and power companies are outstanding and, almost from the time that a majority of these were issued, there has been a steady appreciation in their market value. It has been shown by statistics extending over a long period of years that light and power companies, while earning a much larger rate of return on their outstanding securities than any other class of corporation and at the same time having by far the lowest risk of receivership, have seen their securities selling in the open market at the lowest price, relatively, of any securities generally dealt in.

This situation, however, is now being corrected, and it is evident that it will not be long, comparatively speaking, until light and power stocks and bonds occupy their rightful place among the leading securities in the investment markets of the country. In the last eighteen months, in which all investment markets of the world have been more or less demoralized, the average price of 96 light and power bonds showed a decline of but one point from January, 1914, to August, 1915, while in the same time the average price of 25 representative railroad bonds declined 9.61 points. At the present time the average price of light and power bonds is well above what it was in January, 1914, while the average price of the representative railroad bonds is still below the average of January, 1914.

At the same time a compilation of total revenues of light and power companies of the country, covering more than two-thirds of the entire industry, shows that in the first year of the European war, when earnings of industrial and steam railroad companies were reporting marked decreases, revenues of light and power companies in the aggregate made steady gains and that in no month of the first year of the war did the total earnings of the industry fall below those of the corresponding month of the preceding year. The smallest gain made in any one month was in February, 1915, when the combined revenue of the industry was but two percent larger than February, 1914, but since that time there has been steady improvement, until now average gains of more than ten percent are being shown in the earnings of the industry as compared with earnings in the corresponding months of the preceding year.

The last two years from a financial standpoint have been largely a period of readjustment with the electric light and power companies. The expansion of the large holding companies in the light and power field for a time was so rapid that many conservative financial men feared that an era of inflation was at hand and that these companies would be compelled to go through such a process of reorganization as did the steam railroads of the country. But these fears proved to be unfounded. The world-wide tightening of financial conditions just previous to the outbreak of the European war forced a curtailment of this corporate expansion, and the financial and industrial conditions created by the actual outbreak of hostilities were followed by a general retrenchment by these companies, with the result that now they are in a stronger financial position than ever before in their history. Instead of taking on and developing additional properties, they were compelled, because of financial conditions, to begin the intensive cultivation of those already controlled, and the majority of them have found that this has proved even more profitable than the acquisition of new properties and the extension of their undeveloped holdings.

The inherent strength of the light and power companies was shown in this period of stress by the fact that not one single important company, the securities of which were generally held, defaulted its interest or was forced into receivership and, while some of the companies deferred dividends on their stocks, this was done, not because of lack of earnings to pay dividends, but because the money was urgently required for the corporate needs of the company and to meet the demands of the customers for service. Now, with the opening of a new year, the light and power companies of the United States, as a whole, are in position to do their full part and more in helping along the great industrial expansion which is now fully under way, and which their gains in revenues show they are leading.

In this no one will benefit more in a financial way than the holders of the stocks and bonds of these companies. The increase in earnings of the companies will be reflected in the advancing prices of their securities, and the holders of these, after the customers of the companies, will be the beneficiaries of the improved methods of generation, transmission and utilization of electric current being worked out by the thousands of trained electrical men of the country. That these men should have a part in the increase in value of electric light and power securities which their labor makes possible is undeniable. To this end THE ELECTRIC JOURNAL will each month devote more or less space to a discussion of electric securities, paying especial attention in each issue to the stocks and bonds of one or more leading companies, the securities of which have a wide market and which are in position to profit largely by the wonderful growth of the light and power industry as a whole, the full possibilities of which are as yet only beginning to be dimly realized by some of the leading men in the electric generating and distributing industry.

NEW BOOKS

"Principles and Practice of Cost Accounting"—Frederick H. Baugh. 180 pages, illustrated. Published by the author. For sale by THE ELECTRIC JOURNAL. Price \$3.00.

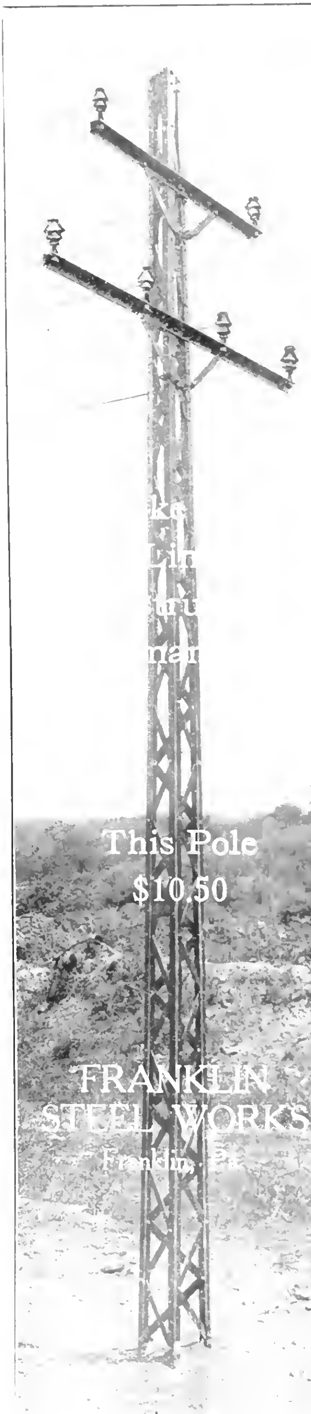
The author discusses the objects and advantages of cost systems and shows the distinction between financial accounting as kept by most concerns and cost accounting designed to show the complete cost of each article or job treated separately. By the latter method those responsible for production can definitely trace each operation and determine which are profitable. The author assumes that the reader possesses a fundamental knowledge of accounting. He emphasizes the fact that the form and method of handling accounts must be appropriately selected and adjusted to the nature of the work. Costs are classified in the following way:—Specific job costs, departmental costs and process costs, with special chapters for various classifications. An explanation of terms and a plea for uniform terminology is presented. It is hoped that such light as the author throws upon this important field will encourage more intelligent application of accounting principles than has been in evidence in the past. E. D. D.

PERSONALS

Mr. H. R. Westcott, until recently superintendent of construction for the United Illuminating Company of New Haven, has opened an office in the Chamber of Commerce Building, New Haven, Conn., for general engineering practice and will specialize on the investigation, design and supervision of the erection and operation of power stations, mills, electrical installations, etc.

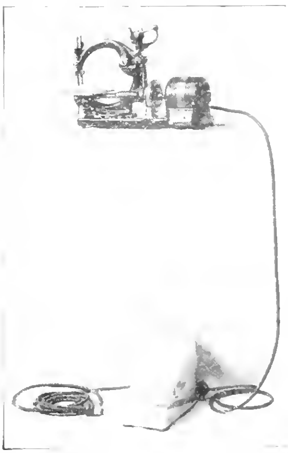
Mr. Paul M. Lincoln, whose connection with the Westinghouse Companies in their operating and engineering activities dates back for over twenty-three years, has become associated with the sales organization of the Westinghouse Electric & Mfg. Company, with the title of commercial engineer. Mr. Lincoln is well known in engineering circles through his active work in the American Institute of Electrical Engineers, of which he was president during 1915. He is a well-known writer on technical subjects and has also been identified with educational work, having for some time filled the chair of professor of electrical engineering of the University of Pittsburgh. Mr. Lincoln was graduated from the Ohio State University in 1892.

Mr. W. S. Long, who has been connected with the Westinghouse Electric & Mfg. Company at East Pittsburgh for the past eleven years, most of the time in the treasury department, has been appointed treasury representative of the Chicago district office of the company.



A NEW SEWING MACHINE DRIVE

A new type of motor for the Wilcox & Gibbs domestic sewing machines is being placed on the market by the Westinghouse Electric & Mfg. Company. The motor is smaller than those previously used and is direct coupled to the machine shaft. The speed of the motor, and hence of the needle, is under perfect control by the operator from a special foot pedal supplied with the motor. In



this pedal there is a specially constructed resistance, which has virtually an unlimited number of steps similar in principle to a slide wire resistance. This gives perfect speed control from zero up to 1800 stitches per minute. However, as this speed is higher than practicable, an adjustable stop is provided, so that the operator may easily adjust the maximum speed to suit her own taste. Any speed from the maximum to one stitch at a time may be obtained. The acceleration is always smooth regardless of what speed is desired; there is no jerking, no breaking of threads.

No brake is necessary, because the motor very quickly comes to rest, since the large flywheel required with foot power is not included in the drive. The motor is of the compensated universal type, which may be used on any 110 volt circuit, whether it be 25, 60 or 133 cycles. A very good idea of the compactness of the motor may be gained from the illustration, as the small size of the Wilcox & Gibbs sewing machine is well known.

THE N.E.L.A. CONVENTION

The next annual convention of the National Electric Light Association is to be held in Chicago at the Auditorium and Congress Hotels during the week beginning May 22.

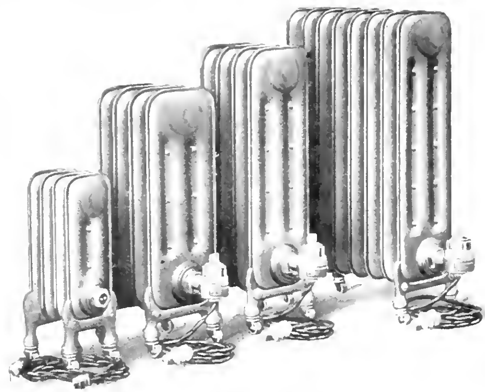
The Railway & Industrial Engineering Company, manufacturers of Burke horn gap switching and protective apparatus and outdoor sub-stations, have moved their sales office from Greensburg, Pa., to the Peoples Bank Building, Pittsburgh, Pa. Mr. L. C. Hart, sales manager of the company, has arranged at their new office an exhibit of Burke horn gap apparatus, in addition to a complete file of blue prints, photographs and data on the application of their outdoor equipment.

MIDYEAR MEETING OF THE AMERICAN ELECTRIC RAILWAY ASSOCIATION

The midyear meeting of the A.E.R.A. will be held on February 4 at the Congress Hotel, Chicago. Addresses and discussions will be given by N. T. Guernsey, general counsel, American Tel & Tel Company, on "Valuation;" by J. D. Mortimer, president, North American Company, on "Rate of Return," discussion by George Weston, Board of Supervising Engineers, Chicago Traction, and P. J. Kealy, Board of Control, Kansas City. In the evening addresses will be given by President Henry, A.E.R.A.; by Thomas Finigan, president A.E.R.M.A.; by Hon. Jacob M. Dickinson, former Secretary of War, and by Hon. Oscar W. Underwood, United States Senator, on "Government Regulation and Our Transportation Systems."

ELECTRIC RADIATORS

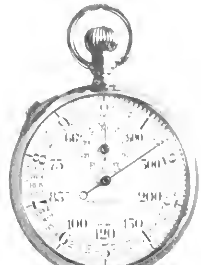
There is no load that is more desirable from the power stations' viewpoint than that of electric heating; and the great advantage from the consumer's point of view are so manifest that only the absence of a thoroughly practical, convenient and economical system of electric heating can account for the failure to find electric heating in widespread use at this time. To meet this demand the Gee Electric Radiator Company, 62[illegible] Peoples Gas Building, Chicago, has developed a line of electric portable radiators which greatly reduce the cost of heating by electricity; operate at a minimum cost of maintenance; give a uniform and steady heat, easily controlled to give any desired degree of warmth. The line of portable units comprises units rated at 200, 500, 750 and 1000 watts. The principle involved in the construction is that of an open coil submerged in a circulating non-corrosive, non-freezing, insulating liquid. The unit is hermetically sealed, therefore no evaporation. The coil is [illegible] the bottom longitudinal passage of the radiators, and by use of the liquid as a circulating medium, a steadiness and uniformity of heat is produced.



These portable units have gained marked favor as heaters for bathrooms, sun parlors, cashier cages; or in fact, may be used wherever additional heat is required. The units may be quickly attached to any light socket and may be easily regulated by means of a three-heat switch. The casters with which they are equipped make them easily transportable from one location to another. The 500 watt size weighs approximately 40 pounds complete, and can be operated for 2 cents per hour in localities where the cost of current is 4 cents per kw-hr.

THE TIME STUDY WATCH COMPARED TO THE USUAL STOP WATCH

There are more men who use stop watches to get close approximations of output than there are of professional rate setters who compile elementary rates. For such men the ordinary decimal watch is not satisfactory because, after the time of an operation has been taken, a difficult mental reduction to output per hour is still required. The time study watch with its computed dial meets the requirements of all factory users. It is divided into tenths and hundredths of minutes and contains figures



distinctly legible that indicate at any point of elapsed time exactly what the corresponding output is per hour. The convenience of this can only be appreciated by using the watch. In the case of short operations, it is good practice to time ten operations and add a cipher to the amount shown on the computed dial. The time study watch has this advantage over all usual stop watches. It is designed to facilitate the deduction of time wasted and automatically reduces the net time to output per hour. Combining all other valuable features, the time study watch also has this additional advantage. To start, push slide towards the stem; reversing the position of the slide stops the watch; push the crown to bring hands back to zero. This watch and a variety of other types are being placed on the market by Mr. M. J. Silberberg, 452 Peoples Gas Building, Chicago, who has carefully investigated the making of efficiency studies in various industries.

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Developments in Electrification

The salient feature which has been emphasized during the past few months in the use of electric power for heavy traction is the concentrated amount of power generated, transformed and used by the various types of apparatus. Economies in weight, space and in performance have all been conspicuous.

In the generating field, turbogenerator outfits have been installed capable of carrying peak loads up to 40 000 kilowatts, which are mounted in the same engine space in which were previously installed reciprocating engine units of only 7500 kilowatt capacity. A striking feature is that the same boilers were used, the increased capacity being secured by improvement in steam economy, as well as intensified operation of the boilers through highly developed mechanical stokers. This demonstrated ability of large turbogenerator units to produce power at low cost is a great incentive to the wider use of electricity.

In the transmission end, distributing transformers are now built of 10 000 kilowatt capacity per unit; transmission voltages as high as 150 000 volts are entirely commercial. For use in connection with subway, elevated and surface lines, rotary converters weighing less than 100 000 pounds are capable of peak swings of 12 000 kw. These units are being installed in the same space formerly occupied by 1500 kw units.

In locomotive and multiple-unit train operation, demands for power commonly run from 6000 kilowatts for multiple-unit trains to 12 000 kilowatts for single trains operated by locomotives. The most conspicuous example of heavy drafts for power is that of the Norfolk & Western Railway, the operation of which is meeting with most enthusiastic indorsement on the part of railway men who have grown up under steam operation.

It is now generally accepted that the contact system for railroad electrification requires overhead conductors. The common voltage is 11 000 volts for alternating current and 1200 to 5000 volts for direct current. What voltage may be expected to prevail for direct current is somewhat uncertain; in other words, present voltages may be considered transitory.

The selection of voltage for a direct-current system controls, to a major extent, the design and character of the equipment, both for the power house and substations, and for the rolling stock. With alternating current the change in voltage is practically that of change in transformer ratios alone, both in the generation and transformer stations and in the equipment.

Coincidentally with the development of large generating and transforming apparatus has been carried on a development of the switching and circuit-breaking apparatus, so that vast amounts of power are handled with certainty. One of the gratifying features of development has been the increasing standardization of the use of electro-pneumatic control, this being now universal for recent subway and elevated applications and extending to approximately 225 electric properties.

Electrical apparatus in general, and especially that for railway use, is now built with increased economy of material and improved efficiency of operation. All of the above considerations promote the advantages to be derived from electrical operation, and in all fields will secure its more extended use.

F. H. SHEPARD

Riding a Hobby

It has been said that Charles Darwin, the eminent English naturalist, worked so continuously over his scientific studies that he lost his sense of musical harmony; thus, though a lover of music as a youth, one of the greatest regrets of his old age was his inability to appreciate a musical composition. This is an extreme case of intense application to a special line of work. The disadvantages of too uninterrupted application are numerous; the sacrifice of health which frequently results is only one of many. An avocation—"riding a hobby"—seems to be essential not only to the enjoyment of good health, but to the fullest enjoyment of the mental faculties and for the prevention of intellectual narrowness. In fact, many of our most prominent men have become famous through their hobbies. Herschel and Brashear, the one a musician and the other a steel worker, made their reputations in astronomy—and both eventually made this their profession. Lubbock, the statesman, is noted for his researches in archeology and entomology. Fabre, a school teacher, has become famous by his studies of insect life. Roosevelt is beloved for his hobbies even by his political opponents.

The electrical industry is especially indebted to men who have had avocations as well as vocations. At the time they made the investigations on which their electrical fame is based, Franklin was a printer, Galvani a surgeon, Coulomb a military engineer, Ohm a professor of mathematics,—the list may be multiplied indefinitely.

In this issue of the JOURNAL is described the hobby of a man who has combined the fascination of photography, and the inborn love of the chase with his own natural bent toward mechanics, in a manner that has been of exceeding benefit to him in the way of health and recreation, and has made him a charming companion in an hour of ease. It is characteristic that an engineer should have pursued his hobby in such a strictly engineering manner.

CHAS. R. RIKER

Single-Phase Commutator Motors

R. E. Hellmund and J. V. Dobson
Railway Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE recent introduction on a large scale of single-phase commutator motors other than the straight series type for heavy traction railway work has aroused interest in the "whys and wherefores" of the numerous possible types of single-phase commutator motors. On account of the large variety of possible types, the average engineer is under the impression that it requires specialized study to find one's way through all the numerous possibilities and to understand even the more essential working principles of the various types. As a matter of fact it requires only the application of two or three very simple fundamental principles in order to understand, at least in a general way, the various possibilities for single-phase commutator motors adapted for railway work. It is intended in this article to give a brief outline of these motors and (in some future articles) to discuss the more detailed working characteristics of the important types.

SOME FUNDAMENTAL PRINCIPLES OF THE SINGLE-PHASE COMMUTATOR MOTOR

Engineers in general are familiar with the classification of direct-current motors which usually distinguishes between shunt motors, series motors and compound motors. Most of these motors are provided with stator field coils for the purpose of exciting a magnetic field which, through its action upon the current-carrying conductors of an armature, produces the motor torque. This field will hereafter be referred to as the torque field. Such a field is required in any alternating current commutator motor, and in many cases it is obtained in exactly the same manner, by stator field coils or equivalent windings. While in direct-current motors it is customary and usually most economical to produce this torque field by a winding on the stator, it is also quite possible to excite this field by a rotor winding. To do this it is only necessary to provide the armature with a second winding and commutator and to send the exciting current through this second armature winding by means of brushes, which are displaced 90 electrical degrees away from the axis of the brushes carrying the armature working current, as shown in Fig. 1. Such a construction has been adopted with direct-current motors in special cases to obtain certain unusual results.

The same thing can be done and has been done to a larger extent with alternating-current commutator motors than with direct-current motors, because with the former, armature excitation brings with it certain marked advantages, as for instance, power-factor compensation and the possibility of shunt characteristics which, as will be shown later, cannot be obtained with stator-excited motors. It is also possible to furnish excitation for the torque field by currents both in the stator and in the rotor. Accordingly, it is possible to classify single-phase commutator motors according to their method of excitation as follows:—

1—Stator excited motors.
2—Armature excited motors.
3—Doubly excited motors.

The latter two classes have not been applied to railway work in this country up to the present. While the armature excited single-phase motor does not always require a separate armature winding, as shown in Fig. 1, it does require additional brushes, and as 25 cycle single-phase motors have numerous brushes anyhow, the addition of exciting brushes has been considered an unwarranted complication. For this reason armature excited and doubly excited motors are not dealt with in detail here.

Modern direct-current motors, in addition to main or torque field windings, are usually provided with commutating field windings, the axis of whose coils is in line with the axis of the armature brushes carrying the working current. Since these coils induce a field which is located at right angles to the torque field it is called the cross field. It is customary in direct-current motors to develop such a cross field only locally near the brush zone.

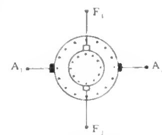


FIG. 1—ARMATURE EXCITED MOTOR

Under especially severe conditions of commutation and tendency to flashovers, certain direct-current machines have been provided with both a local commutating pole winding and a cross field winding distributed over the pole faces. Again, in other direct-current machines the local commutating pole winding and distributed winding have been combined into one single distributed cross field winding. Whenever only a commutating pole winding is used it serves to neutralize the cross fields set up by the armature over the commutating zone only. When a distributed field is also used, its purpose is to neutralize the fields set up by the armature over the entire pole face in order to avoid the so-called field distortion which is obtained if the armature field is not neutralized. The purpose of neutralizing the armature field of a direct-current machine is to reduce the liability of flashovers. Whenever a single distributed field is used in direct-current machines it usually serves the double purpose of neutralizing the armature field over the entire pole face and of furnishing a resultant cross field for the purpose of improving the commutation.

The purpose of the cross field windings as outlined applies also to alternating-current motors. The distributed cross field winding for this type of machine,

however, has a double advantage in neutralizing the armature field. Any magnetic field in an alternating-current motor reduces the power-factor. The torque field and the commutating field are, of course, necessary for the successful operation of the motor; the armature field is unnecessary. It follows, therefore, that the cross field winding, by neutralizing the armature field, not only corrects main motor field distortion, but also improves the power-factor. In some alternating-current motors both a local commutating field winding and a distributed cross field winding have been used to good advantage for the same purpose as in direct-current motors, namely, for furnishing a commutating field and for neutralizing the armature cross field over the entire surface. Again, in other alternating-current motors a single distributed cross field winding for the double purpose of neutralizing the armature field and providing a commutating field has been used. Accordingly, both alternating and direct current commutating motors may be classified with regard to their cross field structure as follows:—

1—Motors with local commutating-pole winding only.

2—Motors with local commutating-pole winding and a distributed cross field winding.

3—Motors with a single distributed cross field winding.

As already intimated, motors of the first type, while the most popular in case of direct current, are hardly ever used for alternating-current motors. Motors of the second type with two separate windings, while giving excellent results with certain connections for very low frequency motors (15 cycles), have so far not been considered sufficiently advantageous for higher frequencies (25 to 60 cycles) to warrant their use in this country on account of the complication of having two separate fields. The third type with a single distributed winding is, therefore, the only type which is at present of practical importance in this country for railway work and, therefore, the following considerations are limited to this type.

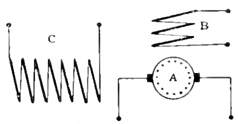


FIG. 2—ELEMENTS OF A SERIES MOTOR

While the torque and cross field windings in an alternating-current motor are primarily used for the same purpose as in direct-current motors, their action is in one respect essentially different. Fig. 2 shows diagramatically an armature *A*, a single torque field winding *B*, and a single cross field winding *C*. As the armature rotates, certain rotational voltages are induced in the armature conductors by the flux of the two fields. In direct-current motors these are the only voltages induced. In alternating-current motors the fluxes set up by the stator windings or the armature are, however, of a fluctuating nature and, therefore, they induce not only a voltage of self-induction, but also, by transformer action, a voltage in any other winding with which they happen to interlink. Thus the torque field interlinks with the individual armature turns and induces by transformer action voltages in them. If these voltages in all the coils between the two brushes be added, as shown in Fig. 3, the resultant voltage is zero and, therefore, does not need to be given any further consideration. Injurious voltages are, however, induced in the coils which are short-circuited by the brushes, since these coils are located with their axis in line with the axis of the torque field. Since the brushes complete a closed circuit for each of these coils, certain so-called short-circuit currents are flowing. This in turn causes arcing at the brushes when the bar undergoing commutation moves from under the brush, thereby opening the circuit. This particular transformer action serves no useful purpose and, in fact, is the only reason why additional commutation difficulties are experienced in alternating-current motors. The cross field interlinks both with the cross field windings and with most of the armature turns, as shown in Fig. 4. Fortunately the short circuited armature coils have their axes at right angles to the cross field and, therefore, the cross field does not induce by transformer action a voltage making commutating difficulties in connection with the armature working brushes. By adding up the voltage induced by the cross field in the armature turns between the brushes it is found, however, that an appreciable voltage is induced by the cross field in the armature. The relative amount of voltage induced in the cross field and the armature by the cross field on account of the fluctuations of the cross field depends principally upon the relative number and distribution of turns of the two windings, and the relative effects of the two windings upon each other are similar to those of the two windings of a regular transformer. If, therefore, with a transformer ratio of 1 : 1 a certain voltage is impressed upon the cross field winding, this same voltage will be induced in the armature circuit by transformer action. On the other hand, if a certain load current flows in the armature, an

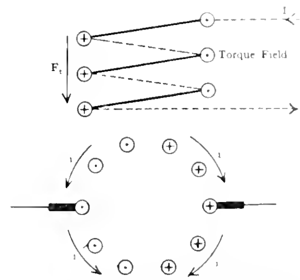


FIG. 3—STATICALLY INDUCED ARMATURE VOLTAGES DUE TO TORQUE (MAIN) FIELD

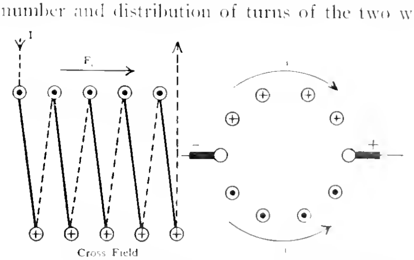


FIG. 4—STATICALLY INDUCED ARMATURE VOLTAGES DUE TO CROSS FIELD

equivalent load current has to flow in the cross field winding. The only difference between the total current in the two windings is, exactly as in the case of a transformer, a certain magnetizing current necessary for exciting or inducing the cross field. With the various types of motors, this transformer action between the cross field winding and the armature can be made use of in various ways, namely, the voltage can be impressed upon the cross field winding and induced in the armature, or again, the current can be made to flow through the armature and compensating currents in the cross field windings can be caused to flow by transformer action. Finally, it is possible to impress voltages upon both windings with a limited exchange of power between the two. With the above principles in mind, it is easy to classify the single-phase commutator motors with stator excitation having a single cross field winding.

CLASSIFICATION OF SINGLE-PHASE COMMUTATOR MOTORS WITH PURE STATOR EXCITATION AND A SINGLE CROSS FIELD WINDING

The simplest form of alternating-current commutator motor is the straight series motor shown in Fig. 6-*A*. In this type of motor all three windings are connected in series and the cross field is wound to neutralize the armature cross field. Since the armature and the cross field are wound for the same number of turns and carry the same current the cross field is practically zero. The commutating characteristics of the motor are, therefore, practically the same as those of a non-commutating pole series direct-current motor, with the difference that both the torque field and the armature currents vary together in phase and in magnitude, and therefore a fluctuating instead of a uniform torque is obtained; another difference, of course, is that the harmful transformer or short-circuit voltage is induced in the armature coils short-circuited by the brushes, resulting in additional commutating difficulties. This type of motor is usually called the straight series motor. Usually the field coils are wound on polar projections, as in direct-current motors. It is, however, quite possible and somewhat advantageous to distribute the main field winding over a number of slots. Fig. 5-*A* shows a distributed main field winding and a distributed cross field winding. From the current directions indicated, it is evident that the same results will be obtained if the two windings are replaced by a single winding, as shown in Fig. 5-*B*. It is quite practical to employ such a single winding in place of the two separate windings in all cases where the two windings are to carry the same current, and where it is not necessary to reverse one of the two windings individually, as required when the motor is to be reversed. Fig. 6-*B* shows diagrammatically a series motor in which the two stator windings are combined into one.

Instead of connecting the cross field winding in series with the armature in order to obtain compensating currents, these compensating currents may be induced in the cross field winding by the transformer action between the field and the armature, as previously discussed. This can be done by short-circuiting the circuit of the cross field winding as shown in Fig. 7-*A*. The flowing of the working current in the armature sets up a sufficient cross field to induce, by transformer action, a voltage in the cross field to drive a current through the field which is equal to the armature current, assuming a transformer ratio of 1 : 1. The working method of the motor of Fig. 7-*A* is, therefore, exactly the same as that of a straight series motor, with the exception that a very small cross field exists. While Fig. 7-*A* shows points of contact between the armature and cross field circuit, the short-circuited cross field can be kept entirely separate, as shown in Fig. 7-*B*. This arrangement is, of course, more advantageous in practice, because the cross field circuit will be subjected to only very low voltages and does not need to be insulated for the line voltage. A still

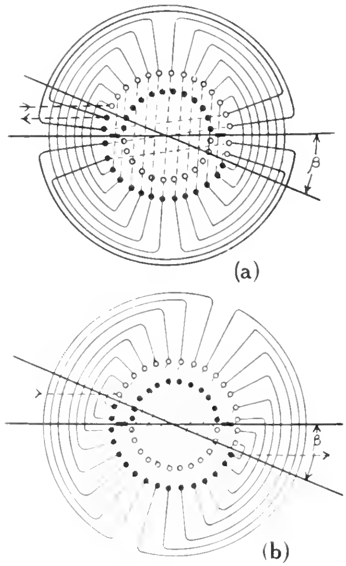


FIG. 5—CROSS FIELD EXCITED SERIES MOTORS
(a)—With two distributed field windings.
(b)—With a single distributed resultant field winding.

simpler practical arrangement is shown in Fig. 7-*C*, where each individual cross field coil is short-circuited, which gives practically the same result. The motors shown in Fig. 7 are often called series motors with short-circuited cross field, or series motors with inductive compensation or neutralization.

Instead of inducing the compensating currents in the cross field by sending currents through the armature circuit, the reverse can be done, as shown in Fig. 8. Here the line voltage is impressed upon the cross field circuit and transformed into the armature circuit by the transformer action between it and the cross field. Fig. 8-*A* shows again certain common points for the two circuits, but in practice the armature circuits may be completely separated from the line, as in Fig. 8-*B*. The motors shown in Fig. 8 have frequently been called

repulsion motors, but it is generally believed now that this name should be abandoned.

Instead of impressing either the entire line voltage upon the armature circuit or the cross field circuit, it is possible to impress a certain voltage on each of the two circuits, as shown in Fig. 9-*A*. The two voltages are in this case taken from two separate parts of the transformer. Instead of doing this, they may, of course, be taken from the same part of the transformer, as shown in Fig. 9-*B*, with a part of the transformer furnishing current to both circuits. Again, it is possible to design the two circuits so that they can receive the same voltage, which leads to Fig. 9-*C*.

Instead of impressing upon the two circuits a voltage in the same direction, it is also possible to impress two voltages in opposite directions, as in Figs. 10-*A* and *C*. Figs. 6 to 10 vary from each other only in that the line power is fed differently to the various circuits and, therefore, it is logical to classify the motors along such lines. Accordingly, all single-phase commutator motors may be classified as follows:—

1—Series fed motors, with power fed to a single circuit containing armature and cross field winding in series connection. (Sometimes called straight series motors; or series motors with conductive compensation, or conductive neutralization; or conduction motors).

2—Armature fed motors, having two circuits with power fed to the circuit containing the armature. (Sometimes called series motors with short-circuited cross field circuit; or series motors with inductive compensation, or neutralization; or conduction motors).

3—Stator (cross field) fed motors, having two circuits with power fed to the circuit containing the cross field stator winding. (Sometimes called repulsion motors; or transformer motors; or commutator induction motors).

4—Doubly fed motors, having two circuits with power fed to each of the circuits in the same direction. (Sometimes called series repulsion motors; or transformer conduction motors; or transformer series motors).

5—Reverse doubly fed motors, having two circuits with power fed to each of the circuits in opposite directions. (Sometimes called reversed series repulsion motors; or reversed transformer conduction motors; or reversed transformer series motors).

In comparing the motors of the last four types, as shown in Figs. 7-*A*, 8-*A*, 9-*A* and 10-*A*, it will be noticed that in principle they are really all one and the same connection diagram, the only difference being that the middle lead *M* of the Fig. 9-*A* is shifted into different positions. By shifting the lead *M* of Fig. 9-*A*, for instance, until it coincides the left lead *L*, an armature fed motor is obtained. On the other hand, by shifting the lead *M* of Fig. 9 -*A* until it coincides with the right lead *R*, the stator fed motor shown in Fig. 8-*A* is obtained. By shifting the lead *M* beyond the right lead *R* of Fig. 9-*A*, the reverse doubly fed motor shown in Fig. 10-*A* is obtained. In other words, the straight doubly fed motor may be considered as the fundamental type of which the armature fed, stator fed and reverse doubly fed motors are simply special cases with zero or reverse voltages in either of the two circuits. The Figs. 7-*B* and 7-*C*, 8-*B*, etc., are only natural developments for practical use based on the above fundamentals.

In all the figures discussed so far, the torque field carries the armature current which, for the same reason as in direct-current motors, gives a series characteristic to the motor. It has been pointed out that, on account of transformer action, the current in the cross field must be approximately proportional to the armature current and, therefore, approximately proportional to the load of the motor. It is, therefore, quite possible to obtain series characteristics by exciting the torque field with the cross field current instead of the armature current. In other words, having in an alternating-current motor two currents which are proportional to the load, either one may be used in the torque field coils for obtaining series characteristic.

Another way of obtaining the same results is to use the sum of the currents instead of either of them singly. Again, it is possible to obtain similar results by using the difference of the two currents, if they differ appreciably, by making the transformer ratio between the armature and the cross field different from 1 : 1. It is evident that if either of the two currents are proportional to the load that their sum and difference will be approximately proportional to the load also.

Instead of using the currents directly, there is the further possibility of inserting series transformers in any one or any number of the leads carrying the armature or the cross field current, or the sum or difference, choosing transformer ratios of any desired kind and combination.

Accordingly, all alternating-current motors with series characteristic may be classified as follows:—

1—Motors with torque field excited by the armature current.

2—Motors with torque field excited by the cross field current.

3—Motors with torque field excited by the sum of the armature and cross field current.

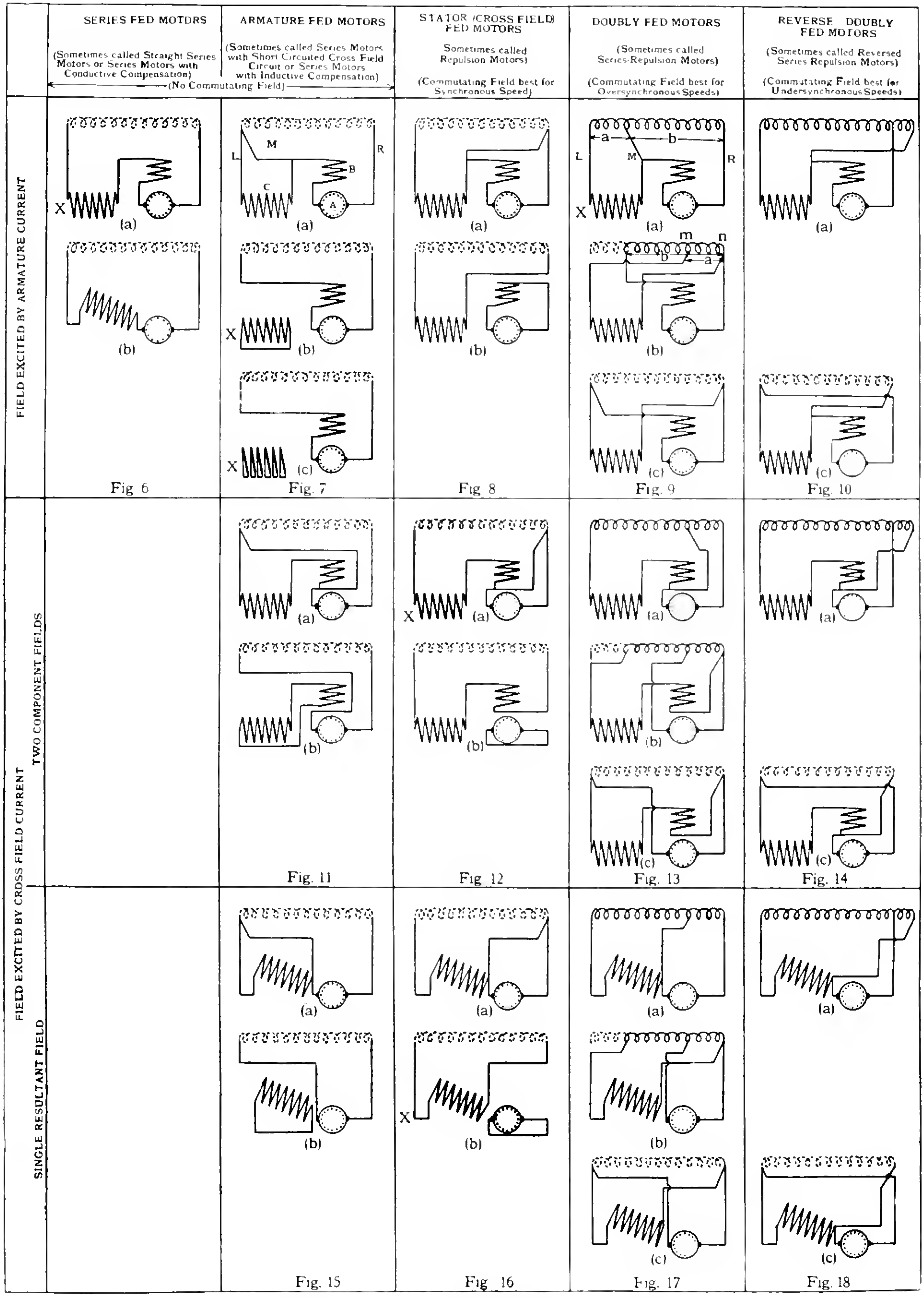
4—Motors with torque field excited by the difference between the armature and cross field current.

5—Motors with torque field excited by a transformer current.

It is now evident that by making various combinations for feeding power into the motor and for exciting the torque field many different motor types may be obtained. Figs. 11 to 31 all represent motor types corresponding to those shown in Figs. 7 to 10, inclusive, the only difference being that the torque field is excited by different currents, all of which are proportional to the load. Figs. 11 to 14 have the torque field excited by the cross field current. Fig. 11-*A* corresponds to 7-*A*, 11-*B* corresponds to 7-*B*, 12-*A* to 8-*A*, etc.

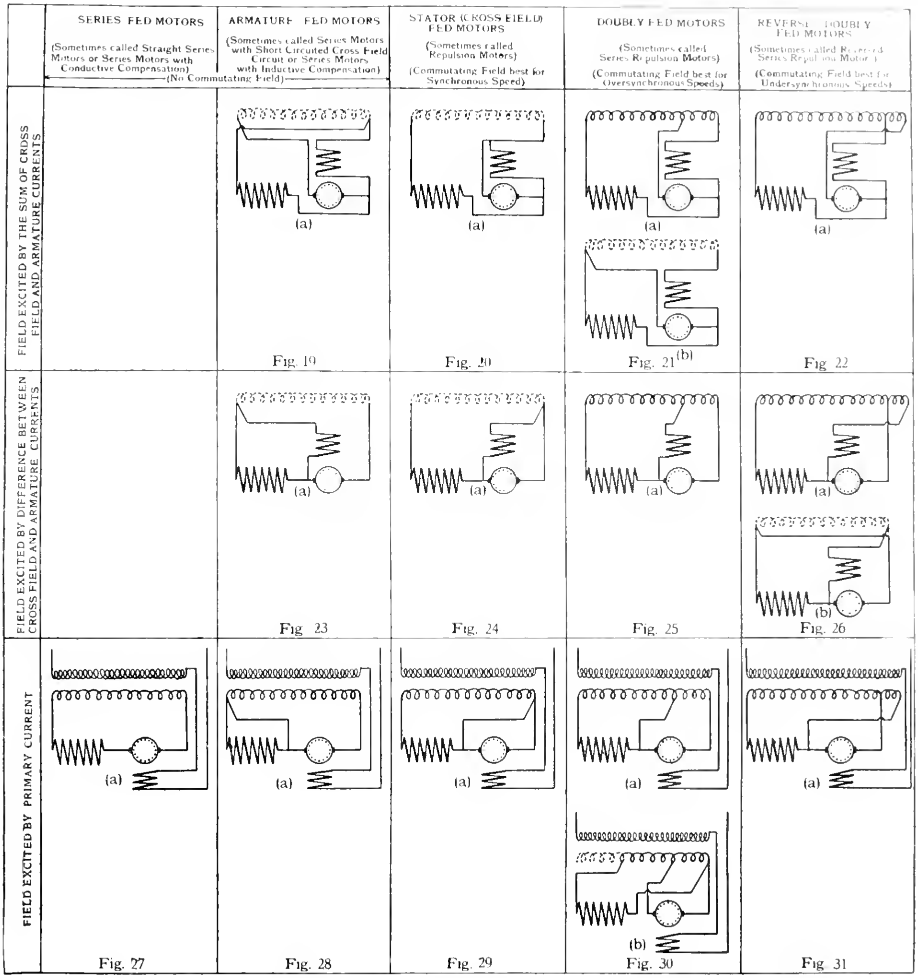
With Figs. 11 to 14 the torque field winding and the cross field winding carry the same current, and they may under certain conditions previously mentioned be combined into one single winding. By doing so, the Figs. 15 to 18 are obtained corresponding to the Figs. 11 to 14. Figs. 19 to 22 are possible motor connections with the torque field excited by the sum of the armature and cross field current. Figs. 23 to 26 are possible motor connections with the torque field excited by the difference of the armature and the cross field current.

The number of possible combinations for a transformer excited torque field is so numerous that a complete classification is almost hopeless. The primary cur-



FIGS. 6 TO 18—CLASSIFICATION OF SINGLE-PHASE MOTORS

Types used in this country up to the present time are designated by the letter *X*. Transformer is shown dotted where it may be omitted.



FIGS. 19 to 31—CLASSIFICATION OF SINGLE-PHASE MOTORS

See Figs. 7(b) and 7(c) for possible modifications of Fig. 28; Figs. 8(b) and 8(c) for modifications of Fig. 29; and Fig. 9(c) for modification of Fig. 30.

rent of the transformer may be equal to the armature or cross field current, the sum or difference of the two and their various combinations, and there are also possibilities of using all kinds of transformer ratios and of combining the transformers so as to add or subtract their voltages. One of the many possibilities is shown in Fig. 32. Except where special results are desired, there is hardly any reason for using secondary transformer currents instead of the motor currents without transformation for exciting the torque field, because additional transformers, of course, mean additional expense and complication. In cases where a main transformer is available, however, it is possible to use the primary current of this transformer, as this is also about proportional to the load for exciting the torque field. Figs. 27 to 30 show some of the possible motor types with the torque fields excited by the primary transformer current.

The question arises as to why a number of the possible motor types shown are, or may become, of practical importance, especially insofar as all of them give nothing but approximately the same series characteristic. The reasons for using one or the other type under various conditions are many.

RELATIVE MERITS OF DIFFERENT METHODS

The series fed motor has the advantage that it can, without change, be used for both alternating and direct current operation, and it is, therefore, advantageous where such a condition has to be met. The armature fed motor permits the separation of the cross field winding from the line voltage and, therefore, has certain

advantages with regard to the insulation of the cross field. The stator fed motor permits the separation of the armature circuit from the line voltage and, therefore, has certain advantages with regard to the insulation of the armature. The stator fed, doubly fed and reverse doubly fed motors have certain advantages, with regard to commutation, over the series fed and armature fed motors. The two latter types do not provide for a commutating field. It so happens, however, in the three other types that the transformer cross field is of such phase as to induce in the short-circuited armature coil by rotation a voltage which counteracts, to a certain extent, the harmful sparking voltage. It further happens that this cross field is of approximately the right strength for compensating the harmful sparking voltages at synchronous speed with the stator fed motor. For this reason stator fed motors are best adapted for operating near the synchronous speed. For similar reasons, doubly fed motors are best adapted for operating speeds above synchronism, and reverse doubly fed motors are best adapted for operating speeds below synchronism.

In considering the relative merits of the various methods of exciting the torque field, it should be mentioned that all motors with the torque field excited by the armature current have the marked advantage that the torque field is always exactly in phase with the torque currents in the armature. This is the most efficient condition, because as soon as the torque currents in the armature are out of phase with the torque field the torques obtained with the same current and the same field strength are less than when there is no phase displacement between the two.

One of the principal reasons for using any of the other torque field excitations is that, under certain conditions, they give somewhat better commutation. With the torque field connected in series with the armature, the harmful sparking voltage and the counteracting voltage induced by rotation in the cross field are not always exactly opposed to each other, so that they may form a harmful resultant voltage. Especially for high-frequency, low-speed motors, better results may be obtained when the torque field is excited by the cross field current. The same is true with regard to motors in which the torque field is excited by the sum of the two currents. On the other hand, motors in which the torque field is excited by the difference of the two currents give the best commutating conditions in high-speed, low-frequency motors. The motors excited by the primary transformer current also give better results for low speeds than motors excited by the armature current.

The motors which are stator fed have one marked advantage over all other motors, and that is that they may be built for most any existing line voltage. The armature voltage of single-phase commutator motors must, on account of commutating considerations, always be relatively low, and the types shown in the attached table with the transformer dotted can, therefore, be connected to an exsting line voltage only if such line voltage is relatively low. With the stator fed motor it is, however, possible to choose any desirable transformer ratio between the armature and the cross field and, therefore, such a motor can be designed for any line voltage suitable and practicable for other types of motors. For this reason the motor types shown in Figs. 12-*B* and 15-*B* have become particularly popular for industrial work.

Of further importance in connection with the choice of the type of motor are the control arrangements involved in connection with the various types. As a rule, those motors which have only two leads, as for instance, Figs. 6, 7-*B* and 7-*C*, 9-*C*, 10-*C*, 11-*B*, 12-*B*, etc., will give the simplest control arrangements. Again, motor types which can be designed for higher voltages, and therefore smaller current, like the stator fed motors, will usually call for switches with smaller current-carrying capacity, and will for this reason be more advantageous. On the other hand, it must be considered that motors with the sum of the currents in the main field are disadvantageous in so far as they require very heavy switches in the main field circuit.

In many practical applications it is further desirable to weaken the field of the motor in starting, because when the motor stands still no compensating commutating voltage can be induced, and because it is therefore desirable to keep the harmful transformer voltage small. It has been found quite practical in such cases to make the transformer ratio between the armature and cross field, and consequently the current ratio, different from 1 : 1, and to vary the field strength by shifting the torque field from one of the circuits to the other; that is, by using two types of connections for the same application. This is especially advantageous with motors that have to operate over a large range of speed. It is thus quite logical to operate a motor reverse doubly fed below synchronous speed, stator fed around synchronous speed and doubly fed over synchronous speed.

In view of the very close relationship in the connections as well as in the essential working characteristics, and the fact that the change from one scheme to the other is mostly accomplished by changing the connections, it does not seem advisable to attempt a very complicated system of nomenclature. In everyday practice it seems quite sufficient to designate all of the motors of the table simply as series motors. Where more detailed information is required, the names, "series fed," "armature fed," "stator fed," "doubly fed" and "reverse doubly fed" are quite sufficient for any of the diagrams shown under these headings. Only in exceptional cases may it be advisable and necessary to mention how the torque field is excited. This simple classification should be sufficient, because usually only one or two of the possible types designated by these headings are of practical importance. These more important types are shown in heavy lines in the figures, and are further indicated by a letter *X*. The series fed motor, Fig. 6-*A*, has been used extensively in railway work where both alternating and direct current operation were required of a motor.

The armature fed motors, Fig. 7-*B* and Fig. 7-*C*, especially the latter, represented until recently the standard type of motors for straight alternating-current railway work. The stator fed motor, Fig. 12-*A*, is being used to some extent as a starting connection for railway motors, while the stator fed motor, Fig. 16-*B*, has been used extensively in connection with industrial motors. The doubly fed motor shown in Fig. 9-*A* is being used as a running connection for railway motors, while Fig. 9-*C* is a convenient connection for smaller doubly fed motors used as auxiliaries on electric cars and locomotives, as well as for industrial work. The reverse doubly fed motor, Fig. 14-*A*, has served as a starting connection for railway motors. Even though these are the only stator excited types which have been used so far in this country, as far as the writers are aware, it is of course quite possible that some of the other types may be used to good advantage, but it is unlikely that there will be more than about ten different types of stator excited series motors at all popular.

This discussion has been limited to series motors with a single torque field winding. In special cases it may be convenient to provide two or more torque field windings, each of which carries one of the possible currents previously discussed.

A purely stator excited single-phase shunt motor or motor with shunt characteristics is practically inopera-

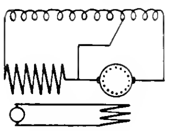


FIG. 32

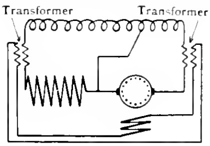


FIG. 33

FIG. 32—DOUBLY FED, SEPARATELY EXCITED FIELD
Equivalent to two-phase.

FIG. 33—DOUBLY FED FIELD
Inductively excited by sum of cross field and armature current.

tive. A shunt connected coil for exciting the torque field would have its flux shifted about 90 degrees against the impressed voltage, while the armature current in the same motor would be shifted only a small amount against the impressed voltage. This means that the torque field and the torque current in the armature are considerably out of phase and that the torque obtained with a given field and armature current will be very small. Such motors would consequently have a very low weight efficiency. Their use will, therefore, be restricted to cases in which certain results may be obtained by bringing the field and current into phase by adding resistance in the field circuits or by designing an especially inductive armature circuit, or both. Shunt connected motors have also been used to some extent as short-time transition connections in connection with series motors.

Similar conditions apply to stator excited compound-wound motors. While it is possible to build a motor similar to a compound-wound direct-current motor with a series and shunt coil for the torque field, such a motor would practically not adjust its field with the load. If in any alternating-current apparatus a constant voltage is being impressed upon a coil, the flux inside of the coil will be given by this voltage, because the flux will always adjust itself to induce a counter e.m.f. equal and opposite to the impressed. If another coil, like a series excited coil, is made to act upon the same magnetic circuit, it will simply change the current in the shunt coil with constant voltage until the currents in the two coils together give the same magnetizing effect as before and induce the same field. This means that the usual way of building compound-wound direct-current motors is not applicable to alternating-current motors.

The only practical means of obtaining a stator excited commutator motor with shunt characteristics for alternating currents is to impress upon the torque field a constant voltage which is about 90 degrees different in phase from the voltage impressed upon the power circuit. This can either be done by means of a phase converter, as shown in Fig. 32, or by means of a polyphase system. In either case the motor is no longer a single-phase motor. Motors being excited by a phase converter have been used in connection with single-phase systems to a limited extent where regenerative control was attempted.

Compound-wound motors with their shunt winding excited by a voltage of different phase may be obtained by means of special arrangements, which are, however, of no great importance in connection with the present discussion. The working principles, the working characteristics, the commutating properties and the like for the more popular types of the stator excited series motors will be discussed more in detail later. The present article was merely intended to give a simple classification and rough idea of the working principles to engineers who are interested in the subject in a general way. It was realized that the work of a large number of engineers, while arousing a certain interest in the single-phase commutator motor, does not require a detailed analysis of the commutating conditions and best arrangements along this line.

The Electrification of Transportation Lines*

N. W. Storer

Ever since the first car was propelled by electricity it has been the dream of the traveling public to have all railway trains moved by that mysterious power. In the early days of electric railways it was thought and freely predicted that the electrification of all steam railways would be an accomplished fact within a very few years. These predictions were based on an imperfect knowledge of the problems involved, a lack of appreciation of the magnitude of the undertaking, and an inadequate idea of the enormous amount of money involved.

Thousands of miles of new electric railways have been built, many of them performing service comparable to steam railways, both with motor cars and with locomotives, but up to date only about 2000 miles of steam railway trackage has been equipped for electrical operation.

The considerations that have thus far influenced the adoption of electricity in place of steam have been: 1—the elimination of smoke and gases from long tunnels; 2—increased capacity and higher class of service for handling suburban traffic in large terminals; 3—increased capacity of mountain grade railways, both for passenger and heavy freight haulage; 4—high cost of fuel and cheap water power; 5—increased capacity, higher class and more reliable service on congested trunk lines; 6—legislation.

TUNNELS

The use of steam locomotives in long tunnels is attended with discomfort to passengers and danger to the train crews under normal conditions of operation, while under extraordinary conditions such as obtain when a heavy train is stopped in a long tunnel, lives may be lost due to asphyxiation. A long tunnel on a railway is usually the "neck of the bottle," the place where the greatest congestion takes place due to the difficulties arising from smoke and gases.

The Baltimore & Ohio Railroad tunnel at Baltimore was electrified about twenty years ago. Since then the Grand Trunk Railway has installed electric locomotives for the tunnel under the St. Clair River at Port Huron, Michigan; the Great Northern has electrified the Cascade Tunnel; the Boston & Maine, its Hoosac Tunnel; the New York Central & Hudson River Railway, the Park Avenue Tunnel at New York; the Michigan Central Railway, its Detroit River Tunnel at Detroit, and the Pennsylvania Railroad has equipped its new tubes under the North and East Rivers at New York for electric operation exclusively. Another important tunnel that has recently been electrified is the Elkhorn Tunnel on the Norfolk & Western Railway near Bluefield, West Virginia.

TERMINALS

There are many incidental advantages connected with terminal electrification, apart from the increased capacity and facilities for handling suburban traffic. The absence of smoke and gases and the comparatively noiseless operation of the trains enhances the value of real estate adjacent to the railways, as well as the value of the railway property. It makes it possible to cover the tracks with buildings of all kinds, hotels, offices, apartment houses or warehouses. The erection of warehouses over freight yards and tracks makes possible the raising of freight cars to upper floors in the building, where they may be quickly unloaded and reloaded and the cars disposed of with the least possible delay.

The increased capacity of the terminal is due largely to the use of multiple-unit trains for handling suburban traffic. The light movements of locomotives and trains in the yard are thus greatly reduced and the number of useful train movements correspondingly increased. The most notable installations of this character in the United States are those railways centering in New York. The Long Island Railway, having a large network of lines on Long Island with terminals at Brooklyn, was the first of these. It has much the largest system of any railway of that character, being almost exclusively a suburban railway with multiple-unit car service. Since the Pennsylvania Station in New York was completed a great deal of the Long Island Railway traffic is taken directly into New York.

In the electrification of the Grand Central Station in New York much greater use has been made of the incidental advantages of electrification than in any other. Both the New York Central and New Haven Railways make use of this station, and both have extended their electrification some distance outside of the city—the former to include the suburban traffic which is handled by multiple-unit trains, while the latter is extended to New Haven, a distance of 73 miles, handling their entire service by multiple-unit cars and locomotives. The New York Central handles its through passenger trains by electric locomotives, but its freight by steam. The New Haven has high-speed electric locomotives for fast through passenger trains, moderate-speed locomotives for heavy passenger and freight service, and slow-speed locomotives for switching.

The Pennsylvania Station is used, as before stated, by the Long Island Railway for its suburban traffic, and also as the terminal for all the Pennsylvania passenger traffic. The locomotives used for these trains are the most powerful passenger electric locomotives ever built. A single locomotive hauls a train weighing 500 to 800 tons up a two percent grade at 30 to 40 miles per hour, and on level track at 50 to 60 miles per hour.

The Pennsylvania Railroad has also recently electrified the main line west from the Broad Street Station

*From a paper read before the Second Pan-American Scientific Congress at Washington, D. C., Jan. 4, 1916.

in Philadelphia to Paoli, and handles their heavy suburban traffic by multiple-unit trains.

MOUNTAIN GRADES

Grades varying from one to three percent are frequently as great handicaps to the movement of trains as are long tunnels. Due to the limited boiler capacity of the steam locomotive, the power it can develop is necessarily limited. Consequently, either the trailing load per locomotive must be limited or the speed must be reduced. Usually both weight and speed have to be decreased, and trains that are normally run on light or level grades with a single steam locomotive are taken up grades with additional locomotives at reduced speeds. On a two percent grade the speed of a freight train is commonly seven or eight miles per hour with steam locomotives, while with electrics, which do not carry their power plants with them, it may be any speed from 10 to 25 miles per hour. Freight train speeds with electric operation on grades will usually be between 14 and 20 miles per hour. Steam-driven passenger trains ordinarily ascend such grades at speeds of 15 to 25 miles per hour. These can be increased to 25 to 40 miles per hour, or higher, with electricity. The average speed can be still further increased due to the fact that no stops are necessary for taking on fuel and water.

Another advantage of the electric locomotive on mountain grades is its ability to hold the train in descending a grade at a steady speed by using the motors on the locomotives as generators, thus generating electric power which is used to help some other train up the hill. Its value consists not only in the amount of power saved as in the greater safety with which the electric trains may descend the grades, as air brakes are used only to stop the trains or in case of emergency. With steam locomotives, air brakes have to be used all the way down a grade, thus causing excessive heating and rapid deterioration of brake rigging and of wheel tires. Regenerative control permits a much higher speed on down grades, which still further increases the average speed. There is thus less interference with traffic in every way and the service is much more reliable. An electrified mountain grade, like an electrified tunnel, can no longer be considered the "neck of the bottle" on a railway.

As an example, the Norfolk & Western Railway is operating their Elkhorn Grade Division with electric locomotives, covering a distance of about 35 route miles of two or more tracks on maximum grades of two percent against the load and 2.6 percent with the load. This road has a very heavy traffic, chiefly of coal, which originates largely in that district. Formerly three huge Mallet compound steam locomotives with mechanical stokers and super-heaters were used to haul trains weighing 3250 tons up the two percent grade at a speed of only seven or eight miles per hour, while two electric locomotives, one pulling and the other pushing, take the same train up this grade at 14 miles per hour. On the light grades one electric hauls the entire train at a speed of 28 miles per hour.

CHEAPER WATER POWER

Several other lines, notably the Spokane & Inland Empire Railway and the Butte, Anaconda & Pacific are handling lighter traffic on generally lighter grades. The last two railways named and the Chicago, Milwaukee & St. Paul, which is now starting operation on the first section of its 440 mile electrification, are all in the mountains of Montana, Idaho and Washington, where coal is quite expensive, steam locomotives are expensive to maintain and there is an abundance of water power. The Spokane & Inland Railway was electrified when built and has operated successfully the past eight years. It is a single-track railway about 120 miles in length. The Butte, Anaconda & Pacific has been in very satisfactory operation for about two years on about 33 miles of line with a fairly heavy mineral traffic. The operation of these two lines was so successful that the Chicago, Milwaukee & St. Paul was impelled to undertake the large electrification mentioned, on which the decreased cost of power, lower cost of maintenance and other incidental advantages are expected to be sufficient to pay a profit on the investment.

In cases where fuel is very expensive, electrical operation will require only about one-half as much fuel as will be needed for steam locomotives to perform the same service. This is due to the great increase in the efficiency of the central station generating units and the electric locomotive.

MAIN LINE

The New York, New Haven & Hartford Railway is the only road in this country which has extended its electrical operation to include all classes of service, and is the only example of extensive electrification for handling a trunk line railway with very heavy passenger and freight traffic. The high-speed passenger locomotives operate regularly at 60 to 75 miles per hour, heavy passenger and express trains at 45 to 60 miles per hour, and freight trains at 30 to 45 miles per hour. Switching in the huge classification yards is done by electric switchers, which are able to operate continuously for days at a time, thus doing the same work as two or three times as many steam engines. Multiple-unit trains are also used for handling suburban service on this and the New York, Westchester & Boston, which is a subsidiary line.

LEGISLATION

The electrification of the Grand Central Station and terminal at New York was forced by legislative enactment on account of an accident in the tunnel. Other cities have since talked of forcing railways to electrify their terminals in a similar manner, but thus far none of them has required it, and it is to be hoped that it will not be done. The electrification of the steam railways in a large city means so much more than the mere change of motive power in order to secure the possible advantages from it, that it should not be undertaken hastily or ill-advisedly.

RESULTS

The results of existing electrifications prove beyond question that any class of service can be handled at least as well by electricity as by steam. They further show that in several classes of service, electricity can handle traffic far better than steam.

The Steam Locomotive—Few people realize what tremendous improvements have been made in the steam locomotive since the electric motor has been applied to railway work. Twenty-five years ago the American type locomotive was the standard for passenger service. It could develop scarcely 1000 horse-power for any length of time. After that came the Atlantic type with the same number of driving wheels, but with greatly increased boiler capacity and heavier weights on driving wheels. Finally, super-heaters and mechanical stokers were added to this locomotive, which is now able to develop 2000 horse-power for an hour at a time at high speeds. There is also at the present time the Pacific type locomotive, with three driving axles instead of two, with the same heavy weight of 60 000 to 70 000 pounds per driving axle, still larger boiler and all other improvements, that is able to develop 3000 horse-power at 70 miles per hour. The efficiency of the locomotive has been greatly increased also, but the cost of maintenance is still high, the mileage without rest is still small, it still gives off smoke and cinders and its capacity is still far less than can be concentrated in an electric locomotive at one end of a train and operated by one crew. It has taken more than 80 years to bring the steam locomotive to its present high state of perfection. There is all the more reason for congratulation in the fact that the electric locomotive in one-fourth of the time has been able to do so much more.

PROBLEM OF ELECTRIFICATION

The problem of electrification of railways covers a great deal more than the locomotives. The steam locomotive is an independent unit which, so long as it has a supply of coal and water on board, can operate over any track. The electric locomotive by itself can do nothing. There must be a power house with steam or water-driven generators, transformers, transmission line, sub-stations and trolley or third rail all between the fuel and the locomotive.

The Central Station—A few years ago every large user of power had to build a power house and everything from power house to locomotive, and every railway required a full corps of engineers capable of handling anything from the boiler plant to the transmission line and sub-stations. Now, however, a great change has taken place. Huge central stations are growing up in some places with great water powers, as at Niagara Falls and in the western mountains, with steam turbines driving generators of enormous capacities. The economies introduced by these large stations, due to high efficiencies and improved load factors, are so great that the small power stations are rapidly becoming a thing of the past, since power can be sold to the consumers at a price so low that they cannot afford to operate their power plants even when they are already installed. In this way the consumer is relieved of all responsibility for power houses and transmission lines. In many cases the sub-stations are also supplied by the power company. This relieves the railways of a great financial burden due to the first cost of the power system, and it also usually gives them power for less than they could generate it themselves. It is confidently expected that as the central stations extend their radius of operation it will be a great stimulus to electrification, since the first cost of the installation has been the chief drawback.

Systems of Electrification—There have actually been three systems, although in America only two have really been active. They are 1—direct current; 2—single-phase alternating current; 3—three-phase alternating current.

Three-Phase power is used in only one small installation in America, and in one or two in Switzerland; but is used quite extensively in Italy, where it has been adopted by the Italian State Railways as their standard. Its characteristic features are that it requires two overhead trolley wires and uses constant-speed induction motors for driving locomotives. The locomotives usually have two constant speeds, secured either by double windings on the motors or by connecting the motors in cascade for half speed and in parallel for full speed. The Italian locomotives operate with 3000 volts on the trolley and apply this voltage directly to the motors, so that no locomotive transformers are necessary. The locomotive is, therefore, comparatively simple and has a minimum weight and maximum efficiency. This type of locomotive also has the characteristic of maintaining constant speed regardless of whether it is going uphill or down, there being only the difference that in going uphill it takes power from the line, while in descending a hill it automatically returns power. The chief reason that has prevented the use of three-phase locomotives in this country lies in the double overhead trolley system. American railway men will not consider the double trolley on account of the complicated construction in yards and cross-overs. It would be impossible also to gain the advantage of simplicity in this country which the Italian locomotives possess, because the service is so much heavier that higher voltages must be used and, consequently, it would be necessary to have transformers on the locomotives.

Direct Current—The direct-current system is the one that is universally used for street railways, as well as all elevated and underground railways in large cities and for most of the interurban railways. The most common potential used is 550 to 650 volts, which is used for all classes of work in cities. For heavy work it is used exclusively with the third rail.

For many years 650 volts was about the maximum used on direct-current railways, because the design and construction of motors and control apparatus had not progressed far enough to make higher voltages possible.

In the last ten years, however, the design of direct-current motors has been greatly improved. Commutation has been eliminated from the troublesome problems of design by the use of the commutating pole and the insulation has been improved so that it is no longer the limit to the voltage; consequently, the trolley voltage has been pushed up by successive steps to 1200, 1500, 2400, 3000, and now even 5000 volts is in use in regular service on one section of the Michigan United Traction Railway. With these higher voltages it is customary to use the overhead trolley, but there are a few cases where 1200 volt current is used on the third rail, and one case where even 2400 volts is so used.

By using 3000 to 5000 volts, the current becomes so small that the current taken by heavy locomotives can easily be collected from an overhead wire and the loss is so low that the sub-stations can be placed 25 to 50 miles apart. Thus the cost of conductors and sub-stations becomes of relatively small importance and electrification with direct current becomes economically possible for many long lines. One 3000 volt installation has been made on the Chicago, Milwaukee & St. Paul Railway. While heavy trains can be operated at this voltage, a higher voltage is preferable if it can be secured with safety. Experience in the operation of 5000 volt equipment indicates that this voltage may be quite satisfactory for both multiple-unit cars and locomotives, as a car has been operated by the Michigan United Traction Company over 14 000* miles at this voltage without a breakdown in the insulation or any other troubles due to the high voltage.

The advantage of the direct-current system for railway work lies largely in the characteristics of the series motor which is universally used. Mechanically, it is simple, rugged and comparatively inexpensive. Electrically, it has speed and tractive effort characteristics that are especially well suited to the work of rapidly accelerating heavy trains with minimum power consumption, as well as of operating them at full speed afterwards. The steep speed characteristics give an automatic division of load among all the motors in a train even with the maximum variations in wheel diameter. The efficiency of the motor is high, and its reliability and "fool-proof" characteristics make it the most popular of all types of railway motors.

The series motor is not well adapted in itself for regenerating energy in descending grades or in stopping trains, so that this has for many years remained almost an undisputed advantage of the three-phase induction motor system. Recently, however, a method has been perfected by which all the advantages of the series motor are maintained and regeneration is also secured, so that now the direct-current series motor may be used for automatically regenerating the stored energy of a train in stopping or in descending grades.

*At the time of going to press, Feb. 12, this mileage has been increased to approximately 21 000 on 5000 volts, with a total mileage of equipment of about 26 000.

Direct-Current Power Supply—It is now almost universal practice to generate power in the form of alternating current on account of the flexibility in raising and lowering the voltage. Three-phase alternating current is delivered to the sub-stations for a direct-current railway, and is there changed to direct current by means of motor-generator sets or rotary converters. The former are usually used for high-voltage lines where high frequency alternating current is supplied. The latter are used more often where low voltage and low frequency currents are employed. The sub-station with this moving machinery has been one of the great objections to the direct-current system in the past, and is one of the points that is to be overcome by the use of higher voltages on the trolley, which permits a greater distance between sub-stations and, consequently, gives a better load factor and requires fewer attendants.

Single-Phase System—The present single-phase system was first proposed in a paper before the American Institute of Electrical Engineers at New York in September, 1902, in which was outlined a plan for using a high-voltage, single-phase current on an overhead trolley wire, transformer sub-stations without attendants, a transformer on each car or locomotive with which to lower the voltage to that required for use with a compensated series alternating-current motor. Immediately afterwards electrical manufacturers in Europe and America started to develop single-phase commutator type motors, and soon a considerable variety of them was placed on the market. The advantage of the single-phase system centers in the high voltage which can be used on the trolley, while at the same time using ordinary voltages on the motor and control equipment in the car or locomotive. The high-voltage alternating current reduces the cost of the overhead conductor and feeder system to a minimum and enables the railway to use sub-stations without attendants.

Examples—The most notable examples of the single-phase electrification are the New York, New Haven & Hartford Railroad, the New York, Westchester & Boston, the Hoosac Tunnel, St. Clair Tunnel, Spokane & Inland Railway, the Philadelphia-Paoli electrification of the Pennsylvania Railroad and the Norfolk & Western Railway on its Elkhorn Grade Division. All the railways in this country that have adopted this system in the last eight years have used power at 11 000 volts on the trolley, 25 cycles. It is possible that still higher voltages may be used, in which event the line losses would be further decreased.

European Standards—The single-phase system with 12 000 to 16 000 volts and 15 to 16.6 cycles has been adopted quite extensively in Europe, especially in Germany and Switzerland, where it has been tentatively adopted as standard.

Types of Single-Phase Locomotives—The commutator type motor has been used on all installations of single-phase equipments with the exception of the Norfolk & Western, which has adopted the split-phase loco-

variations of these schemes are found in gearing motors to hollow shafts surrounding the driving axle, which are connected thereto by long flexible springs, as on the New Haven freight locomotives; also the combination of gears and side rods, such as on the Norfolk & Western locomotives. These both have the advantage of carrying all motor weight above the springs, so that the dead weight carried by the drive wheels is reduced to a minimum. Other variations are found in Europe, where the so-called "Scotch yoke" is used on the three-phase locomotives of the Italian State Railways, and various forms of parallel rods are used for connecting motors to drive wheels in Switzerland and Germany.

When the electric locomotives were first proposed it was the general idea that it would be extremely simple to connect the driving wheels with the motors. It was also thought that the low center of gravity of the electric locomotive would make it ride very much better and safer on the track at high speeds. It is now recognized that the high center of gravity of the steam locomotive is one of its virtues which should be utilized as far as possible in the design of electric locomotives; also that the connection between the motor and the drive wheels is one of the most vexatious problems of the locomotive. However, it is quite possible at this time to undertake the electrification of a large system, to analyze the work to be done, to design the locomotives and other equipment necessary and to foretell the performance and the costs not only of the installation, but of the operation, with a degree of accuracy that is unexcelled in any other line of engineering work. There are experts for every branch of the work from power house to locomotive and, with the efforts of these men properly co-ordinated, remarkably successful results can be assured.

motive, which takes single-phase current and, by means of a phase converter (which is a single-phase induction motor of half the total capacity of the main motors on the locomotive), is able to supply three-phase power for the main motors, so that the latter are simply standard three-phase induction motors with all of the characteristics pertaining to that type of motor. The Norfolk & Western locomotive has two speeds, 14 and 28 miles per hour. It automatically regenerates power in descending grades.

The single-phase system thus permits the use of locomotives with either series characteristics or with the induction motor characteristics.

Mechanical Design of Locomotive Transmission—One of the greatest problems connected with the electric locomotive is purely mechanical. It is the problem of the transmission system between the motors and the driving wheels. Ordinary spur gearing is quite satisfactory for street cars or even multiple-unit cars. It is also used on large locomotives, but it has the disadvantage of placing a heavy, non-spring supported weight directly on the driving axles which, especially if used for high-speed work, causes a rapid deterioration of the roadbed. Many schemes have been proposed and used for avoiding these difficulties. For high-speed locomotives the motors are often operated at the same speed as the driving axles. This can be done either by mounting the motor armature on the axle, as on the New York Central locomotives; or mounting the entire motor on a hollow shaft surrounding the axle, as on the New Haven passenger locomotives; or by mounting the motor in the cab and connecting it to the drive wheels through a system of parallel rods and a jack shaft, as on the Pennsylvania locomotives at their New York terminal. Other

Electric Locomotives for Spotting Service

ON THE NIAGARA JUNCTION RAILWAY

R. K. CULBERTSON

ELECTRIC locomotives are daily demonstrating their ability to handle steam railroad rolling stock successfully in service around industrial plants. This service requires much "spotting" and general shifting of cars, as well as hauling them from the steam railroad interchange points to the manufacturing plants, and vice versa. As railroads are compelled to charge for all service other than dropping cars at a plant, it will undoubtedly prove economical for industrial plants to purchase their own locomotives, or in some cases, where the industrial plants are close together, the problem may be solved by the formation of a corporation for the purpose of giving this service. Where electric power is available, the electric switching locomotive is the best and most economical means of meeting this condition.

The Niagara Junction Railway electrification, at Niagara Falls, New York, which is the most extensive of its kind in America, may be used in illustration. The main track of this road is about four miles in length, while the total length of sidings is approximately eleven miles. The function of the road is to act as an interchange or connection between steam railroads and a group of about twenty-five large industrial plants located along its right of way. In addition to this service the railway is called upon to make many local movements at the various plants, such as placing empty cars at specified points for loading, weighing, etc.

Under steam operation, which was used for approximately twenty years prior to the electrification of the road, two locomotives handled the work. One of these locomotives was of the four-coupled switcher type, weighing 78 400 lbs.; the other was of the six-coupled switcher type, weighing 98 100 lbs. The number of cars handled by these locomotives was about the same as handled by the electric locomotives, viz., 1200 to 2000 per month.

Under the present system the operations of the road begin at seven o'clock each morning except Sundays

and legal holidays. The two locomotives, each having a crew of three men—an engineer, a conductor and a brakeman or switchman, are started out from the engine house and proceed to the yardmaster's office, approximately a mile distant, where orders are received, such as finishing work left uncompleted the night before and placing empties at industrial plants. This work done, one locomotive is then run to the New York Central Railroad interchange, the other to the Erie Railroad interchange, to secure loaded cars for the plants along the line. After these train movements have been completed, the locomotives return to the various plants, there to be used for switching, "spotting," etc. All of these movements come under the supervision of the yardmaster, who is advised from the railway offices as to the numbers of the cars at various locations to be handled. He also receives advice direct from the traffic departments of the various industrial plants on the railway when cars are to be placed for loading or unloading, spotted or weighed. At about three o'clock in the afternoon the locomotives make another trip to the interchange points for loaded cars.

FIG. 1—LOCOMOTIVE TAKING TRAIN OVER THE MAXIMUM GRADE ON THE NIAGARA JUNCTION RAILWAY
This grade is about 3200 feet long, is approximately one percent and is practically all on a curve

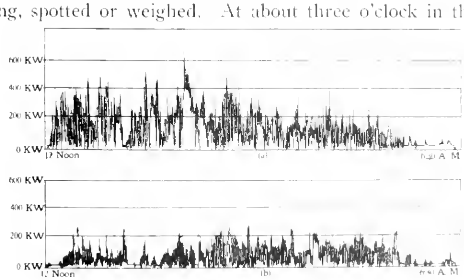


FIG. 2—TRAFFIC LOAD CURVES
(a) Heavy traffic fluctuations. (b) Average traffic fluctuations.

One of the very interesting features in the operation of the road is that cars are not weighed by the railways for the purpose of determining the charge for handling the cars on a ton-mile basis. The railroad companies pay the Niagara Junction Railway on a "per car" basis for delivering the cars to the various industrial plants. This same basis applies in the case of the industrial plants delivering loaded cars to the railroads. Additional charges are made on a "per car" basis for each local movement, including "spotting" and for each car weighed.

A substation located in one of the power houses of the Niagara Falls Power Company supplies power to the railway. The equipment of this substation consists of one 750 kw, 6 phase, 25 cycle, 600 volt commutating-pole rotary converter having a 300 percent maximum overload capacity; two 400 k.v.a., single-phase, 22 000 volt transformers, and control switch. The load on this substation is variable, as indicated by the load curves, Fig. 2 (a) and (b), which show the fluctuations due to the inherent characteristics of switcher locomotive service for heavy and average traffic, respectively.

With the exception of about a mile and a half, the overhead construction is of the catenary trolley type, which is especially well adapted for service where switching operations predominate. The mile and a half mentioned is on a siding where direct bracket type suspension is employed. The turn off into an industrial yard, shown in Fig. 3, gives an idea of the type of construction used, and shows the deflectors installed to prevent the pantograph from catching. The height of the 0000 trolley wire is twenty-two feet in most places.

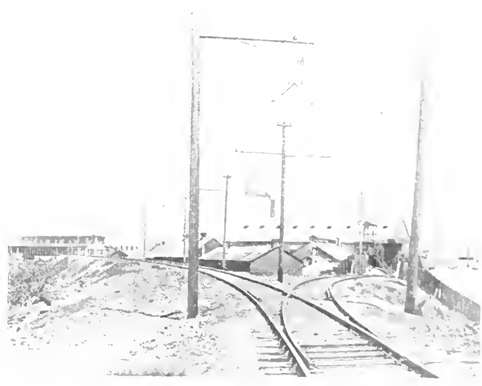


FIG. 3—SECTION OF THE MAIN LINE AND A TURNOUT INTO AN INDUSTRIAL YARD

Where entering loading sheds is only about nine inches higher than the pantograph at its lowest position. The average spacing of the hangers on the catenary construction is fifteen feet. On sidings where direct suspension is used, specially designed flexible hangers are used. These may be seen in Fig. 3. Another very interesting feature

FIG. 4—TWO 60 TON BALDWIN-WESTINGHOUSE LOCOMOTIVES
Ready to leave the yardmaster's office after receiving orders for the day.

of the overhead construction is the special insulated cross-over installed at the intersection of the Niagara Junction Railway and the International Railway, which is the local street railway at Niagara Falls. Lightning arresters are placed along the distribution system wherever the line goes underground. A 350 000 circ.mil cable supported on the poles along the track forms the return circuit. This cable is connected electrically to the rails at intervals of about seven hundred feet.

The locomotives are of the standard gauge, double-truck type, designed for freight and switching service. They were built for double-end operation, having a centrally located steel cab, with a sloping hood at each end. The general characteristic features of these locomotives are:—

Weights

Mechanical parts	83 000 lb.
Motor equipment	26 040 lb.
Control equipment	5 468 lb.
Air brake equipment	4 060 lb.
Forced ventilation equipment	532 lb.
Total	120 000 lb. or 60 tons
Weight on drivers	120 000 lb.
Weight per driving axle	30 000 lb.

Dimensions

Total length between coupler knuckles	35 ft. $2\frac{1}{4}$ in.
Rigid wheel base	7 ft. 4 in.
Total wheel base	25 ft.
Diameter of outside driving wheels	36 in.
Diameter of inside driving wheels	31 in.

Performance

Track Profile.	No. of Cars, Each Weighing 45 Tons With Load.	Max. Speed, Miles per Hour.
Straight level	50	10.50
½ percent grade	24	9.75
1 percent grade	14	9.75
2 percent grade	8	9.75

The maximum tractive effort with clean dry rail is 30 000 lb.

The electrical equipment consists of four Westinghouse commutating-pole, field control, direct-current, 600 volt motors, with double-end unit switch control. Both the motors and control are particularly well adapted to meet the severe conditions incident to switching locomotive service. Current is collected from the trolley wire by means of a double-shoe pantograph. Extra long and drooping horns are used on both locomotives as a means of preventing damage which might otherwise be done to the overhead construction at turnouts. These pantographs have proven conclusively their ability to collect large amounts of current with very slight wear on the contact surfaces.

As the locomotives are in constant service every day it is necessary, in order to insure continuity of service, that they be inspected at regular intervals. This is done every other day in the engine house, shown in Fig. 5. These inspections, which are principally on the mechanical parts, with special reference to the brakes and brake rigging, require usually about one hour. Once each month each locomotive is given a thorough inspection, which consists, in general, of the following:—

1—All parts of the locomotive are freed from dust by means of compressed air.

2—Commutators and brushes are inspected and the motor air-gap checked up.

3—Oil in motor bearings is measured and more oil added if needed.

4—Compressor and blower motors are carefully inspected and oiled where necessary.

5—The control apparatus is gone over, replacing arc boxes when necessary. The reversers and change-over switches are taken apart, cleaned and lubricated. Contacts, both main and interlock, are cleaned and then greased slightly with vaseline. The sequence of the switches is then checked.

6—Grid resistors are examined for loose connections.

7—The blower motors are tried out to see that proper direction of air circulation is given.

In changing over the Niagara Junction Railway to electric operation it has been found that there has not only been a saving in the cost of operation and maintenance, but also the superiority of the electric locomotives has been evidenced by greater flexibility and efficiency in the handling of the cars. With electric loco-

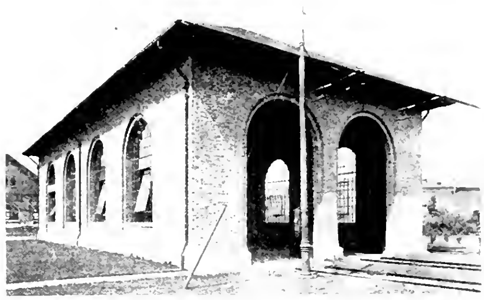


FIG. 5—LOCOMOTIVE INSPECTION HOUSE

motives it is possible to start and stop much more quickly than with steam operation. Much time is also saved in moving cars but a few feet or even inches, as is often required in "spotting" service. The "handwriting on the wall" indicates that the electric locomotive will be the correct solution of many problems, of the type of those described above which faced the management of the Niagara Junction Railway.

An Outsider's Impressions of the Norfolk & Western Electrification

T. C. Wurts

ONE evening last Fall the "spectator" boarded N. & W. train No. 4 bound for Norfolk, Va. In his younger days he had been a pioneer in the steam railroad business, but of late had given up business cares and spent his time traveling, looking for anything that was new and interesting. Having located his berth, he adjourned to the smoking compartment and soon became engaged in conversation with fellow travelers. Finally one of the travelers, evidently connected with the railroad, asked whether any of those present had been over the road since the mountain section had been electrified. The spectator said that he had read of the electrification; had heard that the locomotives were in successful operation and hoped some day to stop off and see them actually in service. He was thereupon invited to stop over and inspect this installation, which the railroad man assured him was epoch-making.

The next morning, therefore, the spectator arose for an early breakfast before alighting at Bluestone for an inspection of the power house. While he was sitting in the diner the train came to a stop and then started off again. A gentleman sitting opposite remarked that they must have changed engineers, as he had been awakened every time a start was made all night, due to the jerking of the train, but that this start had been made so smoothly that he did not know when the train began moving; also the train increased in speed with unusual rapidity. Soon they again came to a stop, and again the start was made without a bump or a jerk, the train seeming to glide smoothly away. In a few moments, however, as they speed around a curve, the spectator was able to see the reason for this agreeable change in the manner of handling the train; they had entered the electrified zone, and an electric locomotive had been attached just ahead of the steam engine. He, therefore, asked the dining-car conductor whether this were a regular thing.

"Yes," was the reply. "We are getting to the worst part of the grade now, and since the electric service was started an electric locomotive pulls us up the grade. The steam engine shuts off, and the electric engine hauls steam engine, train and all. The electric only stays with us about 15 or 16 miles, but I have seen them couple up when we were 20 minutes late, and when they left us at the end of the run we were on time."

The spectator was presently handed a note from the railroad man regretting that he had been compelled to leave the train unexpectedly and enclosing a note for the electrical superintendent who, the spectator was assured, would see that he was shown through the power house and might be given a ride on one of the electric locomotives. This was much to his liking, as he had found that the best way to determine the true value of an installation was to inspect it when not in the company of some over-enthusiastic attendant who might give him a prejudiced viewpoint.

Arriving at the power house, the spectator presented his letter. During his inspection of the power house he had a chat with the load dispatcher, and found that the power house had already experienced short peaks as high as 21 000 kw, and that loads of 15 000 and 18 000 kw for periods of 10 and 15 minutes, were not uncommon. From observation, the load dispatcher said that about 7000 kw was delivered to a single locomotive while starting a train. The load factor was somewhat above what had been expected when they started operations; they were then hauling a record tonnage over the road and for that reason their load was heavy, but at no time had it been necessary to use more than two of the generators, and they always had one in reserve in case of emergency.

"We thought at first," continued the load dispatcher, "that regeneration might give us some operating troubles."

"Regeneration!" inquired the spectator. "What's that?"

"You see," replied the load dispatcher, "when an electric locomotive is going down hill with a train it holds the train electrically. The motors are used as generators and power is pumped back to the line."

"Do you mean to tell me that one of these engines will go down a hill with a train and not use any air brakes to hold it back?"

"Yes, sir; that's right."

"I don't see how it can be done, but perhaps I shall learn more about it this afternoon. Well, did you have any trouble with this regeneration, as you call it?"

"Absolutely none. You see, we have relays that handle this situation. The fact is, I have been connected with the operation of power houses furnishing railroad load for the past ten years, and this one is easier to operate than any I have been connected with."

"Is there any reason why this plant should be easier to operate than any other?" asked the spectator.

"Yes," was the reply. "I believe the fact that the entire plant, locomotives and all were furnished by one company has had a great deal to do with it. In designing the apparatus, each part was laid out to meet the requirements of every other part. The result is, we

have a composite system instead of a hetrogeneous collection of different systems, such as might have been the case had the apparatus of numerous makes been purchased, which is so often the case."

Having completed his inspection of the power house, the spectator next visited the locomotive inspection shed. There he found several locomotives standing in the yards, and one inside the shed over the pit evidently being inspected. Having nosed around independently for a time, he sought out the foreman. The latter was soon located, an energetic railroad man who had been brought up in the steam school, but who had thrown in his lot with the electrical work when it became apparent that this was the motive power of the future.

"What are these idle engines in the yard? Are they out of commission, or is business simply slack?" were the first questions put by the spectator.

"No, indeed," replied the foreman. "You see, the railroad company bought twelve engines to take the place of some thirty odd Mallet steam locomotives, but the work of these electrics so far exceeded our expectation that it is very seldom that more than seven are ever required, and we have never been called on for more than eight. No, these engines are not lying idle because business is slack; on the contrary, we are getting more and more business each month."

"I take it," said the spectator, "that this is a sort of electric roundhouse, and that the electric locomotives return here at the end of each day's run."

"Correct," rejoined the foreman; "but you see we're not as busy as they are at a steam roundhouse, because when we send an engine on the road we don't see it again for about two weeks."

"Do you mean to tell me that the engines run continuously for two weeks without being touched?"

"Well, not that," replied the foreman; "at the end of each run, before a new crew is called, the engine is given a superficial inspection, which takes about an hour. Then the engine is sent out on the road again with a fresh crew. You see, with this arrangement it is only possible to work the locomotives 22 hours a day, instead of 24, as we might if it were not for giving them this inspection. We ought not to complain, however. Every car on the road has to be inspected at least once a day, and I don't think we should begrudge a couple of hours a day to each locomotive. Once every two weeks the engine is brought here for a day and we give it a thorough overhauling, tightening up any bolts that may be loose, and doing any other little job that may be necessary."

"Then, as far as your end of the job is concerned, the electrification has been a success."

"Indeed it has," was the enthusiastic reply. "We have gotten rid of the maintenance of about thirty Mallets, and are doing their work with a total of twelve electrics, resulting in much smaller maintenance charges."

The spectator was still somewhat skeptical about the success of the whole proposition. This talk with the shop foreman certainly didn't sound as though the electrification had not been successful;—still he made up his mind that he would not be convinced until he had been out on the road and had actually seen the engines in operation.

Just at this moment a long train of empties drawn by one of the electric locomotives came by and stopped outside the inspection shed. Grasping this opportunity, the spectator climbed aboard and introduced himself to the engineer and fireman, presenting his pass. By this time, the signal for which the train had stopped having cleared, the train moved on. From the engineer the spectator now learned they were pulling a train of ninety empties, which they were going to deliver to different operations in the coal fields. He looked back along the train to see whether he could catch sight of the caboose, but found that he could not. In fact, although he looked back several times from advantageous points, it was not until nearly the entire train had been delivered that he was able to see its end.

After leaving Bluestone the train proceeded up a slight grade, and at the end of about a mile and a half they approached a single-track tunnel. The engineer told him that the eastern portal of this tunnel marked the beginning of the long, downhill grade to the coal fields. He suggested that the spectator stand behind him so that he could watch the meters drop off almost to zero as the train went over the "knuckle," and then build up again as more and more of the train threw its weight against the locomotive, until finally the entire train was being held back by the braking action of the motors.

"This is one of the greatest things that has come with electrification," volunteered the engineer. "We used to drop down the hill here with our air brakes in the old steam days. It was 'nip and tuck' for our compressors to hold up the air. Getting down the mountain used to consist in applying the brakes, releasing them to recharge the train line, and then applying again. Quite frequently we would all but run away before we were down, and there wasn't a man of us that didn't breathe a sigh of relief every time he got his train to the bottom. Now we drop down by regeneration, and always have the train line fully charged so that we have plenty of air to make a quick stop at any time."

The train proceeded down the grade, and when the coal field was reached several stops were made for the purpose of delivering empties to the various coal operations. Having gotten rid of all the empties, the locomotive proceeded to a nearby storage yard, and there found a train already made up and ready to leave.

In a few moments a signal from the train crew indicated that all was ready for the start. The front engineman acknowledged this signal and, signaling to the pusher engine, opened up on his locomotive. It was only now that the spectator realized for the first time the enormous power of these engines. As the start was made the front engine moved ahead, pulling the slack out carefully from a part of the train. Then it seemed to hesitate for a few seconds, but as the rear locomotive added its force the front locomotive seemed almost to

leap away in comparison to steam acceleration. Almost before the spectator knew it they had completed the acceleration and were moving up the hill at constant speed. The spectator looked back along the train and saw the rear locomotive coming up with apparently no effort, forty car lengths to the rear.

"What is your load?" he asked the engineer.

"Full tonnage—3250 tons," was the reply.

"And the grade?"

"Two percent," replied the engineer.

"You didn't get a train away on this grade as easily as that with steam engines, did you?" inquired the spectator.

"I should think not," was the reply. "I have been on a Mallet on the head-end of a train with two others on the rear pushing, and have worked for half an hour trying to get started. When we did get started three of us could only pull up the grade at about seven miles per hour, while now two of these electrics get away easily and up the hill at fourteen miles an hour.

"So then you think these engines are better than the old Mallet?"

"Two to one," was the emphatic reply. "These engines are easier handled, cleaner, more comfortable and better in every way. It used to take us about twenty minutes to get through Elkhorn Tunnel. Often by the time we got out we would be half dead from the gases. Now it takes us two and one-half minutes, and there is no smoke. I could make three round trips with one of these engines, and not be nearly as tired when I come in as I used to be after a single trip on a Mallet. I have been running a steam engine for over twenty-five years now, and I am through with them. Only the other day I had a chance to get a passenger run and turned it down. I won't take one of those runs until they put electrics on them."

"Me, too," chimed in the fireman. "As long as I can hold one of these runs I don't want anything better—no more firing, no more watching a stoker, no more dirt, no more stops for coal and water. About all I have to do now is to go around and see that my oil is feeding O.K. If I had an automatic oiling system and an automatic bell ringer I would be out of a job."

"We will appreciate these engines more when the cold weather comes," added the engineer.

"Yes," said the fireman; "sometimes they used to call us out around two and three in the morning, and then we had to back down the mountain with nothing to break the wind but the tender. Many's the time I have wondered whether I would reach the bottom before I was frozen stiff. Now we can close our windows, turn on the heaters, and have all the comforts of home. When we were backing down, the engineer was on the wrong side of the road and it was hard to see. Now we are on the front end whichever way we go, and don't have to go on a turntable to be turned around. We are always clear out in front where we can see all that is going on. No more steam engines for me, thank you!"

After this enthusiastic outburst, all three lapsed into silence and nothing was heard in the engineman's cab but the hum of the motors. The spectator reflected on the way in which this train was steadily climbing up this heavy grade with apparently no effort. Never in all his varied experience had he seen anything so impressive. He had heard of the millions that were being spent by this railroad company on the installation, had rather casually followed the scheme in the technical journals, but had never been able to see why it was that all this money was being spent—what justified this huge expenditure. Now he saw—this expenditure was not only justified, but the electrification was one of the triumphs of modern engineering.

Locomotive Weights

F. E. Wynne

There are two general types of electric locomotives; one with all of the locomotive weight on the drivers, the other with a portion of the weight carried on pony or bogie trucks. Switching and light freight traffic are handled satisfactorily by electric locomotives with driving axles only, as is also some passenger service at moderate speeds and heavy freight at low speeds. In high-speed passenger and heavier moderate-speed freight service, idle trucks are more necessary.

Switching and freight services require a locomotive capable of working near the slipping point of the wheels without exceeding the overload capacity of the electrical equipment. In passenger service, high speed is demanded more frequently than great tractive power, and locomotives entirely adequate for a particular passenger run may be incapable of slipping the wheels at every start.

High-powered locomotives are inherently heavier than those developing less power at the same speed. Also within reasonable limits, locomotives of the same type with equal weights will develop power in proportion to their rated speeds. For example: A locomotive to develop 500 horse-power at 18 miles per hour may be built to weigh 35 tons, while one to give 1000 horse-power at the same speed will weigh approximately 44 tons. However, a locomotive to produce 500 horse-power at nine miles per hour will also weigh 44 tons.

The minimum weight of locomotive for a given service may be determined from the weight of trailing load, average car weight, speed, grades and curves, together with probable train resistance values and assumptions of acceleration rate and adhesion factors. The first step is to find the total draw-bar pull required under the worst running and starting conditions.

In running, the draw-bar pull must just equal the sum of all the forces tending to stop the trailing load, which forces may be termed resistances. Train resistance is the term applied to the friction and windage of a train in motion, and is a variable, rather uncertain in quantity. For freight trains the values shown in Fig. 1 may be used.

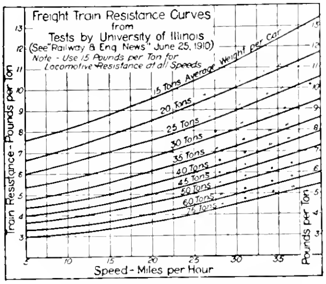


FIG. 1—FREIGHT TRAIN RESISTANCE CURVES

Corresponding values for passenger trains may be obtained from Fig. 2, which is based on the formula:—

$$R = 4 + \frac{V}{10} + \frac{1000}{3600}\frac{V^2}{T}$$

where R = train resistance in pounds per ton.
V = speed in miles per hour.
T = weight of trains in tons.

Curve resistance is also variable, but an average may be taken at 0.8 pounds per ton for each degree of curvature. Grade resistance is exact, and obviously it requires 20 pounds per ton (2000 pounds) for each percent of grade against the load.

The draw-bar pull must be greater in starting than in running by an amount sufficient to accelerate the train at the desired rate. If there were no rotating parts, a force of 91.3 pounds per ton would be sufficient to accelerate the train at a rate of one mile per hour per second. In order to allow for the effect of rotating parts, it is customary to consider 100 pounds per ton as necessary to accelerate at the rate of one mile per hour per second. For other rates the force required is in proportion to the rate of acceleration. Reasonable rates of acceleration which may be used in preliminary calculations are:—

For heavy freight,	0.1 m.p.h.p.s.	10 lbs. per ton
For pick-up or way freight,	0.25 m.p.h.p.s.	25 lbs. per ton
For passenger,	0.2 to 0.8 m.p.h.p.s.	20 to 80 lbs. per ton

With passenger trains, the lower rates would be used for express and limited trains, and the higher rates for local trains.

The adhesion of driving wheels to rails is variable, depending upon rail weight, weather conditions, etc. If the maximum grades are short and infrequent, adhesion up to 25 percent running and 33 percent starting may be assumed. Where the maximum grades are long and frequent starts on grade are required, these figures should be reduced to 22 percent running and 27 percent starting. In using these percentages for adhesion, the total tractive effort for train and locomotive is used, and not the ratio of draw-bar pull to locomotive weight on drivers, the latter practice being commonly followed in rating steam locomotives.

A simple formula for the locomotive weight when conditions are known is:—

$$W = \frac{RT}{20P - L}$$

where W = Locomotive weight (tons) on drivers.
L = All resistance acting on locomotive, in pounds per ton.
T = Weight of trailing load (tons).
R = All resistances acting on trailing load, in pounds per ton.
P = Assumed percentage of adhesion, expressed as a whole number.
RT = Draw-bar pull.

As an example:—What is the minimum weight of electric locomotive, all the weight being on the drivers, to handle 25 cars having an average weight of 40 tons, or 1000 tons total, on a road having maximum compensated grades of two percent for 2000 feet and 1.5 percent for ten miles, a speed of approximately 15 miles per hour being desired on the long grade?

The train resistance is, from Fig. 1, five pounds per ton, and locomotive resistance is 15 pounds per ton. The resistance of a two percent grade is 40 pounds per ton. Allowing ten pounds per ton for acceleration, the starting draw-bar pull is $(5 + 40 + 10)\ 1000 = 55\,000$ pounds. Then assuming 33 percent adhesion, $W = \frac{55\,000}{20\,(33) - 65} = \frac{55\,000}{595} = 92.5$ tons, weight of locomotive required to start the train on the maximum grade.

For running on the two percent grade, the draw-bar pull is 45 000 pounds, and at 25 percent adhesion the locomotive weight becomes:—

$$W = \frac{45\,000}{20\ (25)\ -\ 55} = 101\ (tons)$$

When starting on the long 1.5 percent grade at 27 percent adhesion, the draw-bar pull is 45 000 pounds, and

$$W = \frac{45\,000}{20\ (27)\ -\ 55} = 92.9\ (tons)$$

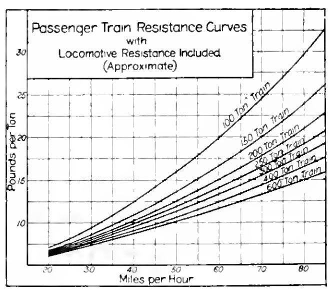


FIG. 2—PASSENGER TRAIN RESISTANCE CURVES

When running on this 1.5 percent grade at 22 percent adhesion, the draw-bar pull is 35 000 pounds, and

$$W = \frac{35\,000}{20\ (22)\ -\ 45} = 88.6\ (tons)$$

The running adhesion on the short two percent maximum grade is therefore the determining feature and the locomotive should weigh not less than 100 tons.

However, judgment must be exercised in the practical application of this method of determining weight. For instance, suppose the short two percent grade is preceded by a long level or down-grade run without stops, so that it could always be taken "on the run;" in such a case a 93 ton engine would have ample weight.

In case idle trucks are used on the locomotive, an allowance of 25 000 pounds for each two-wheel truck, or 40 000 pounds for each four-wheel truck, may be added to the weight of trailing load and preliminary calculations made as previously indicated.

As previously stated, this is a method of determining the minimum weight of locomotive which should be satisfactory from the operating standpoint. Numerous other features affect the actual weight of a locomotive for a specific service, so that it is not always possible to design and build locomotives within the weight derived by this method.

Unevaluated Factors in Electrified Railroad Operation

Q. W. Hershey

In early electrifications costs were a varying quantity both as to the installation and the operation thereafter, but from these early beginnings records were secured which became more definite, so that information was soon available from which figures of probable costs of installation and operation of the heavier systems to come could be adjudged with fair accuracy. While the economies in dollars did not warrant some of the first heavy terminal electrifications, other controlling features compelled the adoption of the electrified method of transportation at those points, chief among which factors were the elimination of noises, dirt, smoke, limitations as to roadway in tunnels, etc.

From the newer, heavier installations a closer knowledge of costs of installation and operation were obtainable. The stability of the electrical equipment in this heavy service set another pronounced record for the consideration of the steam railroad man. Also, and contrary somewhat to expectations, the operation of some of these tunnel and terminal electrifications showed economies, compared with the former steam operation, which were surprising to the general railroad world.

The art of electrified railroading has now reached the status where it is no longer a matter of questionable figures. Certain definite and known items count as an additional cost, among which are the additional locomotive costs above that for steam locomotives; power house and power house apparatus, assuming that the railroad provides its own power supply; the overhead trolley wire or the third rail, and the power transmission line structures along the route; bonds and bonding of the track; feeders to supply the trolley or third rail system; the sub-station apparatus; the lightning protection equipment; the power control apparatus; the telephone and telegraph interference devices. All of these have a definite cost which, together with their respective maintenance costs, are readily determinable.

In an electrification, certain steam equipment is either made obsolete or released from further service at this point. The cost of items which are usable elsewhere and the maintenance costs of these, and of the equipment which is discarded, is accounted as a credit to the cost of electrification. Among these items are the steam locomotive equipment, coaling stations, pumping and watering stations, ash pits and smaller items at roundhouses and at engine division points, some block signals (on account of their decrease in number from the higher speeds usually obtaining in electrified operation where it becomes more advantageous to place blocks farther apart), fewer inspection pits and stations due to the longer engine divisions usually found in electrified operation. The value of these can all be definitely calculated.

The total of all the above costs is finally summed up, along with the higher speeds usually resulting from electrified operation, in a result showing the difference between steam and electric operation per ton-mile of transportation. From this it is determined whether the economies to be secured will justify the electrification.

However, there are a number of factors not yet mentioned, but which have a very distinct value—*the unevaluated factors of electrified railroad operation.* One complete electric engine of the heavier type is at present made up of two cabs. Under each cab, two four-wheel trucks, connected by a Mallet hinge type of coupling, are usually mounted with minimum rigid wheel bases, thus dividing the whole engine into four rigid wheel bases of minimum length; the two sections of running gear under one cab articulating through a permanent coupling with the trucks under the other cab. This gives a very flexible truck and cab arrangement and, in addition, permits of a very uniform distribution of driver weights. The addition of pony trucks provides, then, the most favorable form of design to give easy riding qualities to the locomotive. The difference in the riding qualities of the electric engine as compared to that of the heavy Mallet or high-speed steam locomotives is striking; there is practically no pounding and only slight nosing. In the electric engine, also, as there are usually only two pairs of drivers within a truck, the side rods are lighter, and there is less pounding from this source. Due to the unvarying wheel effort of the drivers, there

is less pounding on the tracks, especially in those engines which have all over-running axle weights spring suspended. All of these factors—easier riding of the engine, more uniform distribution of driver weights, less nosing, less track pounding—result in considerably lower track maintenance costs.

Due to uniform propulsive effort, the electric engine will deliver, per driver weight, greater draw-bar pull than a steam locomotive with same driver weights, but with varying propulsive effort. This, to a degree, has been taken advantage of by raising the tractive coefficient of the electric engine to a higher value than has been allowed in steam locomotive design. Also, if one truck slips, it is possible for the other trucks to absorb the lost effort of the slipping truck; thus the uniform movement of the train is not materially affected. This feature eliminates much of the necessity for slacking down and taking a new start. It further eliminates rack and tear on the trailing equipment, probable breaking of drawheads, etc. The nicely graduated tractive effort within the control of the engineman in the electric engine, both in starting a train and in letting down the tension of a train, are factors contributing to lower costs of maintenance of trailing equipment.

It was long considered a problem whether an electric engine, made rigid and stable enough to supersede the steam locomotive, could provide the unusual feature of "standing against" the load in starting heavy trains. Fortunately, in the Norfolk & Western electrification the ability of the electric engine to "stand against" load while exerting full tractive effort has been thoroughly demonstrated and, due to the graduated control referred to, the operation of the electric engine has proven to be eminently satisfactory in this respect, both in starting and stopping.

With the development of regenerative braking, many new features of operation have been evolved. Taking a heavy train down a steep grade without the application of air, when first propounded, appeared as a fanatic's dream. However, regeneration has proven one of the most important features of the electric engine. It removes all of the strain from the tires of the trailing equipment and eliminates the dissipation of energy through friction, since the airbrakes are not used except to stop or hold a train on a grade. This results in a decrease in tire wear, the elimination of all troubles from hot tires and a decrease in maintenance of the air equipment. Since a constant rate of descension of grades can be maintained, the jarring of trains due to letting down air on long grades, with all of its consequent troubles and costs, is entirely eliminated. This not only affects the secure operation of the train, but materially increases the comfort of passengers on passenger trains. Another great factor of safety is found in the fact that the engineman has at his command at all times, for emergency purposes, the fully charged train line—a condition which does not always exist with the air-braking method. Also, there is less necessity of outside riding on the part of brakemen for the purpose of setting up retainers on long light trains descending grades, thus reducing a hazard of railroading. In addition, the return of power to the line effects a very considerable economy.

Double-end operation of the locomotive, whereby all turning is eliminated, has been a wonderful factor in lessening congestion, and the increased flexibility of operation has inaugurated a new viewpoint in dispatching. With the higher speeds which have usually resulted from electrification, it has also been found advantageous to have block signals set farther apart, resulting in a decreased cost of maintenance of these items, as well as a freer operating condition along the line.

In tunnels there is always a natural tendency to moisture which, combining with the gases of the steam locomotives, usually results in bad trackage. This, too, is eliminated, giving higher speeds and better operating conditions at these points.

While steam locomotives of a class are constructed to be duplicates as nearly as possible, there is always a feeling among the employees, usually based on fact, that one locomotive is a better steamer than another, etc. It is not possible to get as good operating efficiency from a steam locomotive with promiscuous change of crews from one locomotive to another, due to the fact that each crew learns how to operate their regular engine to best advantage. This modifies the ultimate efficiency of steam operation. Not so, however, with the electric engine. Here the source of power is transferred to other hands, where the factors are constant so that the highest efficiency results at that point. The engineman deals only with the manipulation of the levers; he has at his command an unlimited amount of power, and the constant strain to keep the equipment in condition to give high efficiencies has been eliminated. He has also at his command that most desirable feature—the ability to supply power, irrespective of quantity, where and at the time he needs it. This results in higher operating efficiency. The electric engine also requires less light inspection daily, with a resulting longer period on the tracks, thus decreasing the amount of equipment. Double-end operation makes it much more adaptable for switching operation.

As in other commercial operations, a railroad system's scheme of operation and success are founded on the efficiency of two factors—that of the physical property and that of the man, the employee. The two in success are absolutely inseparable, the operation of the one depending upon the part played by the other. Having all conditions most favorable to each results in the highest efficiency of the two collectively. Anything which tends, therefore, to benefit the employee, either by lightening his work, eliminating personal hazard, making his work more comfortable, cementing his fidelity and making him more amenable to orders of superiors (without destroying individual initiative), strengthening his fidelity to the organization and elevating his appreciation of his relation to his employer as a factor in conserving

the public safety,—all go to make up the end to be desired. Anything tending to such an end is valuable, though it may not be easy of evaluation. The employee's work is easier on the electric locomotive than on the steam locomotive. On the steam locomotive the engineer is responsible for keeping his engine in an operating condition. This necessitates constant attention to oiling, inspection of clearances, bearings, tightening of nuts, etc. —in fact, a constant strain not only mentally, but ofttimes physically, tending to cause a fatigue that under prolonged service will become abnormal and will hazard the safety of the traveling public. The importance of this condition has long been recognized, and now the hours of labor for this class of service are all justly regulated by Federal statutes. While running an electric engine is not so easy that this legislation should not apply, the work of the employee has certainly been materially lightened. The engineman is largely relieved of the strain of maintaining the mechanism;—it is a characteristic general to the electric engine that it is usually either perfectly operative or wholly inoperative (with, however, exceedingly high mileage per detention). The electric engineman and his fireman are warm at all times during winter and, in that the engines may be ventilated properly, in summer they are cool. The steam locomotive is excessively hot in summer, while in the winter it is intermittently hot, cold and damp, and if being operated reversed, against the wind, it is benumbingly cold. In the electric engine also the strain of the responsibility for proper power supply is all removed from the engineman.

In the electric engine, when properly designed, meters in the motor circuits are mounted along with the air gauges in plain view of the engineman. From these he is able to tell just what each individual truck of his locomotive is doing. Also, the generally better tractive conditions of the electric engine with its grouped independent trucks usually reduce the number of extra starts which must be made.

When the electric engine was first proposed there went up a hue and cry that electrified operation would put the steam railroad operators out of business, their positions of necessity to be taken by men experienced in the operation of electrical equipment. However, the steam locomotive engineer discovered that he could capably handle the electric engine and, furthermore, that the operation of the electric engine involved greater physical ease and general physical comfort than the steam locomotive, the result being that the engineman has become an enthusiast under the new scheme of electrified operation.

"Safety First" has become the popular watchword of the railroads. It is meant to carry with it a continual red flag against carelessness. While this slogan is a typified ideal, anything which adds to the end of safety must be accepted as of real value, although often not determined readily in actual dollars and cents. In the steam locomotive, the engineer's position is at the extreme rear of the locomotive. Interposed between him and a clear headway is the locomotive itself on one side and before him to an extent. In addition, there is frequently smoke and steam which obstruct his view of signals and roadway. With the electric engine, there is a clear view ahead, so that all danger from inability to see signals properly is eliminated. This gives not only additional security, but it also eliminates the necessity for slowdowns to see signals. These factors undoubtedly have a distinct commercial yet unevaluated worth.

Fundamentally, the success of a railroad enterprise is dependent upon the character of the population which it serves and its relations to that population, which may be to a great degree affected by what the railroad does for the community. The advent of electrified railroading eliminates noise and dirt and the general atmosphere of unpleasantness near the tracks. These conditions improve real estate values, and quite frequently the citizenship along the railroad is bettered. Population usually materially increases along the line of the electrified railroad.

Communities are not disregardful of better service supplied by the public service companies within their midst, and it is one of the proud boasts of a community to point to the improvements and their own better living conditions produced thereby. This tends to eliminate the opposition of the public to the business interests of the railroad, resulting again in a more rapid development of the country traversed, with its consequent direct benefits to the company.

One of the most noticeable features of electrified operation is that there has never been any very serious trouble in starting an electric system. The railroad organization has always been able to meet the new problems resulting from electrified operation in a quiet, easy manner. Furthermore, the operation of electrified systems has not only invariably shown a fulfillment of the engineers' predictions for economies, measured in dollars and cents return, but these have always been exceeded and the electrified operation has invariably proven to be of greater commercial benefit to the railroad than the original figures contemplated. This can be attributable to no other conditions than the many factors, among which are those discussed herein, which are termed the unevaluated factors of electrified railroad operation. These have been of immense value and, while the feasibility of an electrification as a profitable enterprise is generally decided from a measure of profits based on actual figures, it is confidently believed that the proper time for the electrification of a steam road already in existence is when it has been determined that the cost of operation, the interest on the investment and the depreciation and maintenance charges on the new equipment are balanced by the increased net returns to result from the higher economies by electrified operation, and the general benefits and returns expected to accrue from the unevaluated factors of the electrified operation should be accepted as a safe margin of additional profits.

An Engineer at Play

William Nesbit

AFTER GOING over some business matters with the author of this article some months ago, the proposal that we take lunch together was accepted. As usual on such occasions, business was dropped for the time being and the conversation soon turned to the author's hobby, photography. His methods of dealing with the problems encountered in the photographing of animals in the "wilds of New Jersey" were so interesting, and so typically those of the engineer, that it was suggested that other engineers also would be interested in his experiences, covering several years of experimental work; hence the present contribution by one of New York's busy engineers.—[Ed.]

ENGINEERS in general work too hard, due in part to their love for their profession and their ambition to forge ahead to positions of greater responsibility. To many of them work is as play, and expenditures of time and money for recreation and vacation outings appear uncalled for. Sooner or later, however, it may become necessary to slacken up, or pay the penalty. Such critical times are apt to occur very suddenly, and sometimes too late for one to take advantage of the warning. In my own case such a time occurred four years ago and brought an appreciation of the value of good health and the necessity of having a so-called "hobby."

WILLIAM NESBIT

It is fortunate when one technically inclined can pursue an avocation which combines not only a healthy out-of-door diversion, but also some technical interest. I found such a hobby in the development of moisture-proof, high-speed flashlight apparatus for taking photographs of animals by flashlight. This article gives a short history of my experiences in the development of this apparatus.

FIG. 1—TAKING HIS OWN PORTRAIT BY FLASHLIGHT AT SUNRISE

My first outfit consisted of a camera on a stand, protected from rain by a sheet of aluminum,—with a flash pan supported by an upright. The operation was as follows:—

An animal pulling on a bait attached to the tripping wire, or walking into such a wire across a runway, released the familiar old trapper's figure 4 snare, thus causing a weight to fall and trip the shutter. After falling a little further, the weight tripped a trigger, firing a paper cap, which in turn ignited the flash powder. By setting the camera shutter to expose the plate for one-fifth of a second, this arrangement caused the shutter to open just preceding the flash and close automatically just after the flash. The sharpness of the picture was dependent primarily upon the speed of the powder—the greater the speed of the powder, the sharper the picture, if the animal was moving at the instant the exposure is made. Later outfits employed springs for tripping the shutter and firing the flash. Revolvers, well greased with a mixture of rifle grease and beeswax, were substituted in place of caps for firing the powder, which was enclosed in a paraffine dipped pasteboard box. Because the "kick" would shake the camera,

FIG. 2—NOT A VERY INTELLIGENT LOOKING 'POSSUM
But he knew enough to eat regularly all the bait set out except the piece attached to the flash lamp.

when the flash lamp was supported from the camera stand, it was necessary to keep the flash lamp and the camera mechanically independent. A piece of aluminum strap bent to hold the revolver and powder box made a very light combination, which was readily secured to the side of a tree, or other support. The main objection to the employment of revolvers is the strong

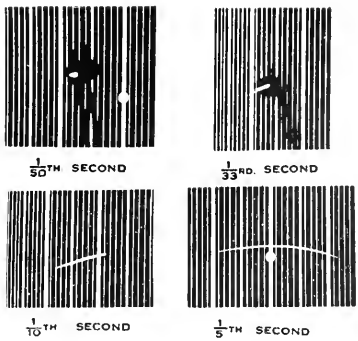


FIG. 3—TESTS ON POWDER SPEEDS

desire of the country boys to annex anything which will shoot.

The pictures taken by the first outfit were usually blurred—always when the animal was moving. This condition was bettered by using powder having greater speed, and by enclosing the powder in a paper box. It was found that slow-speed powders (those having a speed of one-fifth of a second when spread out along a length of 18 inches) were increased in speed 100 percent by enclosing them in pill boxes. The higher speed powders (those having a speed of one twenty-fifth of a second) were only increased about ten percent. These

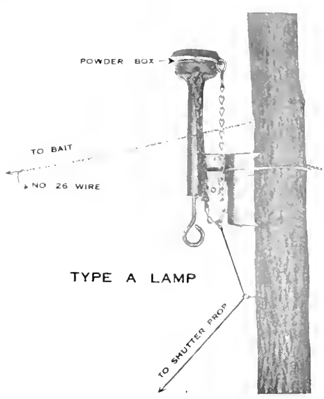


FIG. 4—MOISTURE PROOF FLASH LAMP WIRED TO SMALL TREE

improvements resulted in sharper pictures, but in order to get sharp pictures of running or even walking animals it was found necessary to employ the camera shutter. In this case the shutter must expose the plate only during a portion of the flash.

When it is considered that even with slow-speed flash powders the light is strong enough to take high-speed pictures for less than one-fifth of a second, and with high-speed powders for about one-twentieth of a second, the difficulty in causing the shutter to operate at the exact instant of maximum light of the flash will

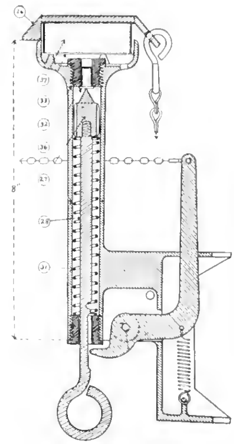


FIG. 5—VERTICAL SECTION THROUGH "TYPE A" LAMP

The lamp frame is made of aluminum with a brass plunger rod *28*, a trigger and bronze compression spring, and a case-hardened iron firing pin *27* which serves to explode a 32 caliber blank cartridge; an aluminum cap *26* fits snugly over the powder box, protecting it from the weather and also furnishing means of tripping the shutter. The camera shutter is equipped with a spring tending to trip it and expose the plate, being restrained by a small aluminum prop, as shown in Fig. 6. This prop is attached through a small brass wire to the chain from the flash lamp cap, so that when the cap is blown upward by the explosion the shutter is tripped, thus exposing the plate at the instant of maximum illumination.

FIG. 6—METHOD OF TRIPPING COMPOUND SHUTTER

be appreciated. Many methods have been tried for accomplishing this, based upon the principle of tripping the shutter at a definite interval of time, following some other operation. The error in these methods is that the small fuses used to fire the powder vary in the time of

their ignition. The result, therefore, is that the shutter usually exposes the plate at the wrong time.

Tests were made to determine whether the plate would be exposed at the correct instant if a part of the energy of the exploding powder were directed to trip the camera shutter. It was feared that such a method would expose the plate too late to receive sufficient illumination. Fortunately, these tests proved that even with powders having a speed of one-fortieth of a second pictures always resulted. With such methods it is immaterial how tardy the fuse or the powder is in ignition, as the shutter is not actuated until the flash has gotten under headway.

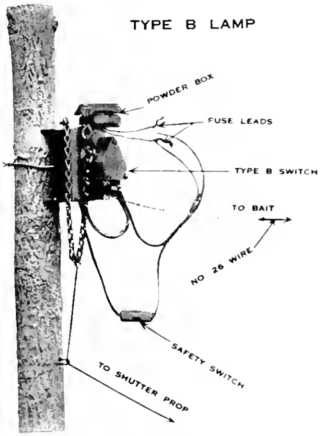


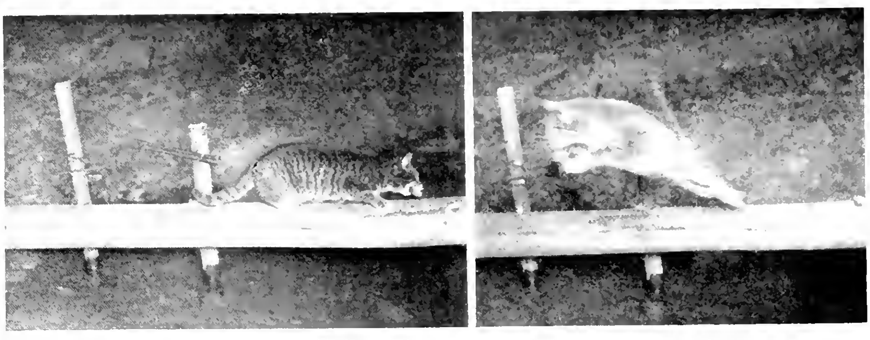
FIG. 7—MOISTURE-PROOF, ELECTRICALLY-FIRED FLASH LAMP

A hollow aluminum casting protects a dry cell and supports a suitable flash powder box, in which the powder is fired by fuses set off by a small switch operated by the animal. Two fuses are employed to ensure an explosion.

FIG. 10—MOISTURE-PROOF CAMERA AND TRIPOD

The camera is made of cast aluminum, three thirty-seconds of an inch thick, except where special reinforcing is necessary to provide mechanical strength. This is too thin to cast aluminum with any assurance of success, and some of the castings are lost as a result. It is believed that the reduction in weight compensates for the increased expense for castings. The aluminum supports are twenty-five inches long, and the camera complete weighs nine pounds.

ture and placed on a tripod. As this type of lamp was fired by a blank cartridge only, it was necessary to be nearby when it was fired. I placed it out in the yard and, with my head as near the ground as far under the lamp as possible, I pulled the string. All the neighbors for a radius of half a mile came up to see what caused the explosion, as the terrific report could be heard three miles away. The concussion blew over the camera and



FIGS. 8 and 9—SUCCESSIVE PICTURES, AN INSTANT APART

Fig. 8—An uninvited and too frequent caller shooting himself with a load of salt.
Fig. 9—The salt takes effect—exposure 1/200 second; it would require 1/1000 of a second to stop motion now.

In order to prove that the highest speed powder would produce pictures when this method is used, I arranged with a manufacturer to compound a charge of the highest speed powder they were willing to make. A semi-enclosed lamp was filled with this explosive mixthe fragments of the lamp casting were distributed pretty evenly over a four-acre field. Had any of the pieces traveled in the direction of China this story would not have been written. However, the test resulted in a picture, although a blurred one. The speed of this enor-

mous charge of powder was probably one seventy-fifth of a second or greater.

The speed of the powder is tested by swinging in front of the camera a seconds pendulum, on the arm extension of which is mounted a conical-shaped polished ball. The light from the flash is reflected back from the swinging ball, and the developed plate produces a line

FIG. 11—A TYPICAL CIRCUIT-CLOSING TREAD SWITCH

shaped like an arc of a circle, as shown in Fig. 3, from the length of which the speed can be calculated.

THE FLASH LAMP

As a result of these experiments I developed three special types of flash lamps for having wild animals take their own portraits by flashlight. Such lamps may be set out of doors for long periods of time, and as a first essential must be moisture-proof.

The Cartridge-Fired Lamp was designed as an improvement over the revolver for igniting the flash, and also to provide a means for operating the camera shutter by means of the explosion. Its construction is shown in Figs. 4 and 5. The lamp is attached to any convenient support just behind and above the camera, and a small wire is carried from the trigger either to the bait or across an animal runway in such a manner that the animal may be induced to take its own photograph.

An Electrically Fired Flash Lamp for the same purpose is shown in Fig. 7. Its operation is the same as that just described. As it has been sometimes found more convenient to mount the parts of this lamp separately, a third type of lamp was developed, having the same parts

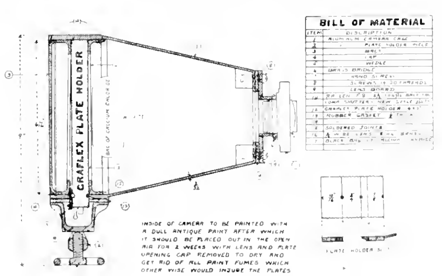


FIG. 12—HORIZONTAL SECTION THROUGH MOISTURE-PROOF CAMERA

After the plate holder is inserted the opening at the side of the camera is made moisture-proof by a rubber gasketed aluminum cap. Focusing is accomplished by removable lens ring, which accommodates the lens to eight or twelve feet focus for small or larger animals. Between the brass lens board and the camera front is a rubber gasket. Thin rubber gaskets are placed between the lens elements and their mountings, and a little vaseline is placed between the lens threads and the shutter threads to prevent any possibility of moisture entering at these points. A small black bag of calcium chloride may be placed inside the camera to absorb any moisture in the air at the time the camera is closed.

as the one just mentioned, but not attached to one another. By a suitable combination of these parts it is possible to obtain automatically two flashlight pictures of the same animal a definite interval of time apart, as

FIG. 13—PHOTOGRAPH OF "TYPE G" FLASH STAND AND MOISTURE-PROOF CAMERA AFTER A BLIZZARD

This treatment injures neither the apparatus nor the flash powder.

shown in Figs. 8 and 9. This is done by attaching to the trigger of the second lamp a weight, suspended from a small copper wire which passes through the flash pan of the first lamp. The heat of the first flash melts this wire and the second lamp is fired an instant later.

In all these lamps the flash powder is protected from moisture by placing it in a thin paper box holding two-thirds of an ounce of powder, which is then dipped in melted paraffine. These flashes are very powerful, as a large charge is required to obtain a satisfactory exposure outdoors with sufficiently high speed to stop motion. The explosion may be heard for a mile or two under favorable atmospheric conditions, and the reflection in the sky has been seen for over five miles. With a lens opening of F-8 and the animal eight to twelve feet from the lens, a shutter speed of one-hundredth of a

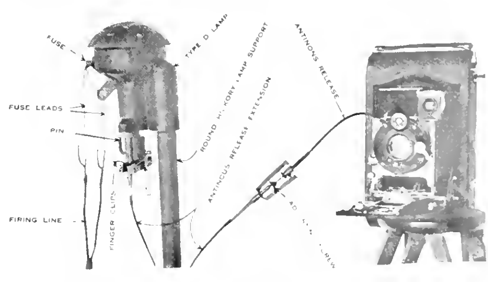


FIG. 14—"TYPE D" SEMI-ENCLOSED ELECTRIC SQUIB-FIRED FLASH LAMP

Connected to a kodak through antinous release extension.

second is required to stop motion in case of animals pulling at a bait, and one two-hundredths of a second is usually necessary in the case of walking animals.

Some kinds of animals do not forget what has happened on a previous occasion. Other animals will not hesitate to fire flashes whenever there is a mouthful of cheese to be had for the fireworks. To provide for the

former class, electric circuit-closing tread switches, such as shown in Fig. 11, may be concealed under leaves, so that the animal will unconsciously fire the flash when it steps on the switch. These are especially useful after an animal has once fired a flash by pulling on a bait.

THE CAMERA

Ordinary cameras have been used for this service and, where they are visited daily, are entirely satisfactory, provided they are completely protected against the weather. However, in damp weather plates will usually not keep in good condition in them for more than one day. Hence a moisture-proof camera was desirable which would keep the plates for protracted periods during the severest weather. After considerable experimental work I developed the camera shown in Figs. 10 and 12, which is light in weight and is entirely moisture-proof. The cameras and the flash lamps will stand exposure to the severest weather, such as shown in Fig. 13, for indefinite periods without deterioration of either the dry plate or the flash powder.

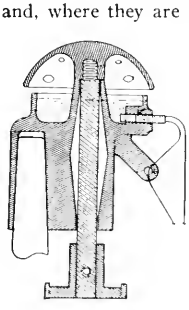


FIG. 15—SECTION THROUGH "TYPE D" LAMP

OTHER HIGH-SPEED FLASH LAMPS

Where the lamp and camera are not left alone, it is not necessary to have them moisture-proof. This is generally the case where the exposure is made by a watcher concealed nearby and for photographing animals from the bow of a boat at night, which is becoming a popular sport among persons spending their

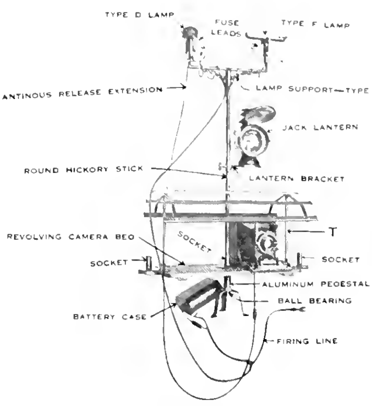


FIG. 16—OUTFIT FOR PHOTOGRAPHING ANIMALS FROM A BOAT

summer vacation among mountain lakes where deer abound. A number of different types of lamps have been developed for this service, all of which depend upon the same general principles for their operation, but which may be somewhat more cheaply constructed. In these lamps the aluminum cap over the powder is not blown off by the explosion, but is merely lifted for a short distance, the motion being sufficient to trip the shutter, as shown in Figs. 14 and 15, through the medium of a special antinous release extension which operates directly the antinous release with which the ordi-

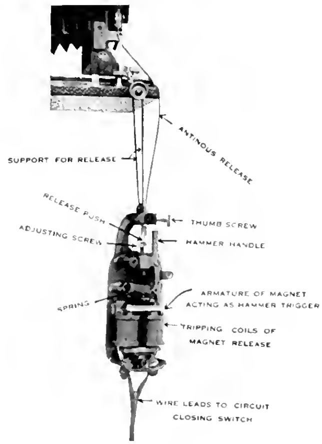


FIG. 17—MAGNET RELEASE FOR TRIPPING THE SHUTTER OF THE CAMERA BY ELECTRICAL MEANS

The action of the mechanism is obvious. The magnet armature releases a spring-actuated hammer which pushes on the antinous release of the camera.

nary camera is provided. An outfit has been especially developed using a pair of these non-moisture-proof flash lamps and one or more ordinary cameras, Fig. 16, for "jacking" or photographing deer, moose and other animals standing along the shores of rivers or lakes. This consists of a horizontal revolving bed carrying the

FIG. 18—A COON WHO IS FOND OF CHEESE SANDWICHES

cameras, jack lantern and flash lamps, all supported by a ball-bearing pedestal, which is usually screwed to the seat in the bow of the boat. When the jack shines on the animal from a suitable distance the flash may be fired by the operator without further adjustments and

with confidence that a satisfactory picture will be secured. The ball-bearing pedestal provides for noiselessly turning the entire outfit for the purpose of locating the animal, and many pictures may thus be secured which would be impossible if the apparatus had to be pointed by turning the boat.

MAGNET RELEASE

Where the distance between the camera and the flash lamp is not constant the antinous release extension previously mentioned is valuable for short distances, and for larger separations the magnet release shown in Fig. 17 has been developed. This release may be operated by hand from a distance, or may be operated by one of the flash lamps by having the vertical movement of the plunger pull an insulating plug from between two spring contacts, thereby closing a circuit from the battery to the magnet coils of the release. This release may also be connected in parallel with the fuse circuit; it will then open the shutter preceding the flash, and if the shutter is set for, say one-fifth of a second, it will close immediately following the flash. This method is of service when high speed is not required, and when it is desired to have the plate receive all of the light from the flash, such as when taking colored transparencies by flashlight.

With the shutter prop method, the shutter is tripped as soon as the movable plunger starts to raise; with the magnet release, the shutter is tripped soon after the circuit through the magnet release is closed. It actually requires approximately one-thirtieth of a second longer for the tripping of the magnet release as determined by oscillograph tests, Fig. 19. The higher the speed of the powder, the greater the speed operation of the movable plunger, and consequently the sooner the magnet release trips the shutter. If this were not so the flash might be over before the release operated and failure would result. An interesting fact indicated by these tests is the short time required to trip the shutter after the circuit through the magnet is closed, namely, 0.03 second. This time is divided up into approximately 0.02 of a second for the armature of the magnet to close and 0.01 of a second for the mechanical travel of the hammer.

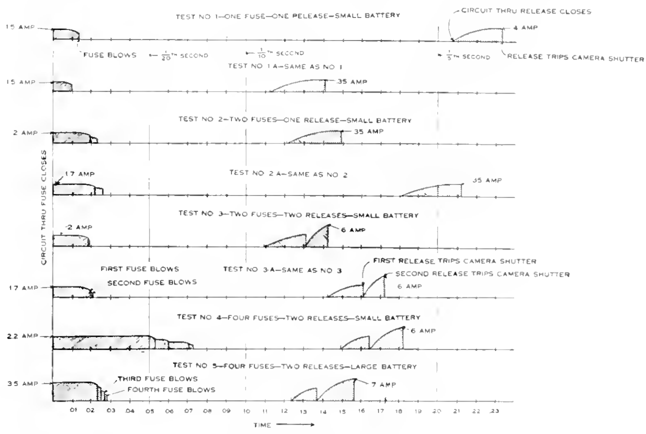


FIG. 19—OSCILLOGRAPH TESTS

Made to determine the time intervals between the closing of the battery circuit through the fuses, the opening of the fuse, the closing of the circuit through the magnet releases and the tripping of the shutter. More than one fuse is used in case more than one lamp is fired simultaneously or to insure the firing of a lamp; two magnet releases are used when it is desired to make two photographs, using two cameras. The flash does not start until some time after the fuse blows, depending upon the explosive nature of the powder and its condition.

GENERAL

Tests with all the lamps described above indicate that powders having a speed of one-fifth to one-tenth of a second give best exposures, although with the shutter prop method powders of one-fortieth of a second speed produce pictures usually under exposed. The tests indicate a wide variation in the time of blowing of the fuse and the closing of the magnet release circuit, due, no doubt, to the variation in the rate of ignition of the flash powder. This indicates clearly why methods depending upon a fixed time of operation of the shutter are unreliable. I have frequently subjected a pile of flash powder to a 1.5 inch spark from an induction coil without causing it to ignite the powder; this is due to the small amount of heat in such a spark when the source is a dry cell.

The apparatus described above embraces the most prominent items so far developed. They have superseded many earlier types. An important feature learned during the progress of this work was a greater respect for the cost of developing new apparatus. The more certain it appeared that the next change in the pattern of any particular item would be the last one, the more certain it would be only the beginning of changes. Each change would probably correct previous defects, but would usually introduce new ones, to be corrected by an additional change. The numerous changes were frequently not necessitated from the viewpoint of improved operation, but on account of the desire to reduce the weight and simplify field operation.

I wish to acknowledge my [illegible] Hon. George Shiras III, whose numero[illegible] during the past six or eight years in the [illegible] Magazine attracted my attention to this [illegible] which has proved so beneficial; also to Da[illegible] the sportman's friend —Mr. Abercrombie sugg[illegible] ment of the energy of the exploding flash fo[illegible] shutter and thus gave the start which le[illegible] thod of developing this apparatus; als[illegible] to Mr. [illegible] who made very complete oscillograph tests [illegible] net release.

The Engineering Evolution of Electrical Apparatus—XX

THE HISTORY OF THE ARC LAMP—(*Concl.*)

F. CONRAD and W. A. DARRAH

THE metallic flame lamp was not directly suited for alternating currents, nor for indoor work, and even after its development the enclosed carbon arc was for a time a very useful light source. But while it contributed largely to future progress, it could not be considered a permanent unit because of its low efficiency, from 1.5 to 2.0 watts per mean hemispherical candle-power. The incandescent lamp, as well as keen competition among arc lamp manufacturers and insistent demand from progressive operating men, all tended toward the removal of the limitations of the arc.

In Europe this situation was partly met by what was known as the intensified enclosed carbon arc, consisting of an arc lamp in which the carbons were much smaller than usual and the current density in the carbons was about double that in the ordinary enclosed arc lamp. This resulted in increased efficiency, but at the expense of the carbon life, requiring increased maintenance. On account of its higher efficiency and white light this lamp was introduced in this country for indoor lighting at about the same time that the metallic flame lamp was becoming generally introduced for outdoor lighting. The efficiency and cost of operation of this lamp were not, however, sufficient to enable it to meet the competition of the more improved forms of incandescent lighting. Similarly the development of larger size, high efficiency tungsten lamps for street lighting necessitated radical improvements in arc lamps for outdoor service.

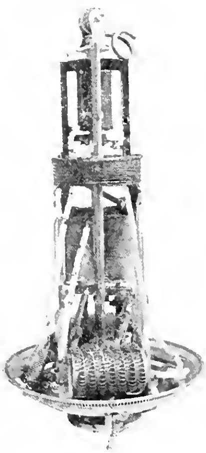


FIG. 47—EARLY BREMER ARC LAMP

In order to get the proper perspective it is necessary to turn backwards for a period of fifty years (until 1844), when Bunsen, a young German chemist, began investigating the effects produced by introducing into the carbon arc various chemical compounds. The immediate result of these experiments was a considerable increase in scientific information on the spectra of the various elements, and also some advances in the electric furnace and the electrolytic reduction of metals. But while Bunsen noticed the increase in brilliancy of the arc, it remained for Bremer, half a century later, to apply this information practically. The period which elapsed between Bunsen's discovery of the scientific principle and its engineering application by Bremer is typical, and in this case was due both to the absence of a demand and the lack of means of applying the discovery. The addition of an impregnating salt to the carbon electrodes may be considered as a logical development at this time, as the carbon arc is the only one known at the present which will maintain itself on alternating current under commercial conditions, and an alternating-current lamp which would equal or better the efficiencies of the metallic flame lamp on direct current was in demand.

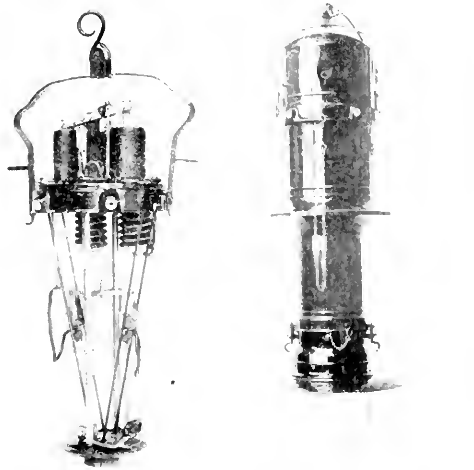


FIG. 48—MECHANISM OF WESTINGHOUSE BREMER ARC LAMP

The year 1898 marks the commercialization of the flaming arc by Bremer in the general form shown in Fig. 47. The introduction of this lamp may be considered a notable advance in efficiency, it reaching values from 0.192 to 0.421 watts per mean lower hemispherical candle-power. In the Bremer lamp, and in most of its successors of this type, small diameter carbons varying from 18 to 30 inches in length were employed. The carbons were usually arranged at an angle of about 30 degrees with each other and usually were inclined downward through guide tubes. A magnetically operated clutch mechanism not very different in principle from that of the enclosed carbon arcs controlled the feeding and separation of the carbons.

These lamps may be considered to be of a semi-enclosed type, as the arc was formed below the typical economizer of the enclosed lamp and maintained within a globe communicating with a condensing chamber for

collecting the "soot," as the soft, white powder formed by boiling away the mineral contents of the carbons was called. The enclosure of the lamp was not sufficient, however, to give a carbon life over twelve to eighteen hours, and even with all precautions taken the globe became so rapidly covered with deposit that it was usually necessary to clean it at the end of the trim to make it transmit the light efficiently.

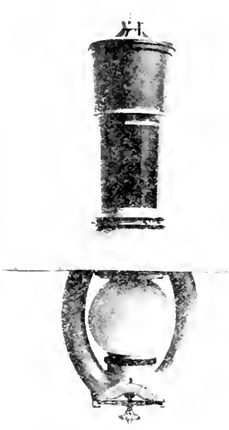


FIG. 49—ADAMS-BAGNAL REGENERATIVE ARC LAMP

The carbons are perhaps the most interesting feature of the Bremer lamp, although as the forerunner of a new feature, later much further developed, the condensing chamber is of considerable interest. Two general types of Bremer carbons were used—the cored, and the homogeneous, depending upon operating conditions. The cored carbons consisted of an outer shell or envelop of ordinary hard carbon, in the center of which was placed a softer core composed essentially of calcium oxide and carbon, although other materials, such as fluorides, etc., were frequently added. The solid homogeneous carbons were composed entirely of an intimate mixture of carbon and mineral materials baked to a hard mass. When operated in a lamp the carbon, which formed the conductor, was volatilized, and the light-producing materials were volatilized into the arc. The result was a very different arc from that of Davy. Instead of a bluish, non-luminous vapor stream between two intensely incandescent carbon points, the electrodes were relatively non-luminous, while the vapor stream was the source of an intense reddish yellow light. The arc was longer than the older arc and very much resembled a flame,—hence the name flaming arc. The marked difference in appearance between the positive and negative electrode was also absent.

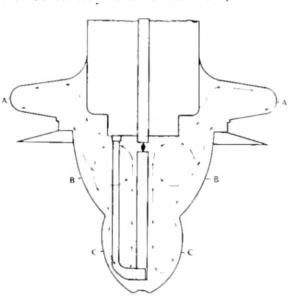


FIG. 50—DRAFT SCHEME OF EARLY ENCLOSED LONG BURNING FLAME CARBON ARC LAMP

aa—Condenser. *bb*—Arc chamber. *cc*—Lower condenser. The heat prevents the gases from condensing on the glass at *bb*. The long arrow points show how the lighter gases are carried by the air currents into the upper condensing chamber. The short arrows show how the heavier gases circulate into the lower section of the globe and condense, leaving the section of the globe surrounding the arc unobstructed.

The work of Bremer was closely followed by that of Blondel, the differences comprising mainly in details. The Blondel lamp was distinctive in the construction of the carbons, which consisted of several concentric annular shells, alternate layers being hard carbon and mineral material, respectively. The carbons, being relatively large in diameter and 12 to 14 inches long, were arranged vertically, one above the other, after the manner of the enclosed carbon lamps.

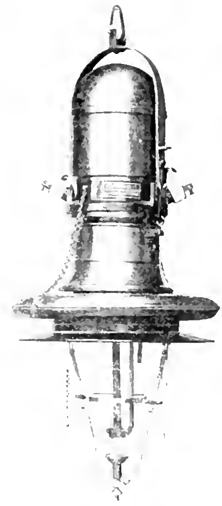
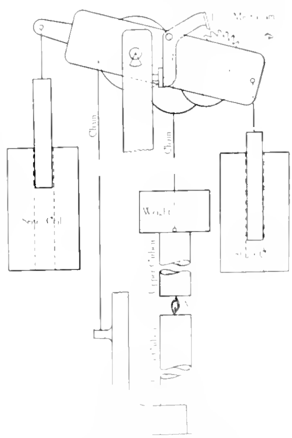


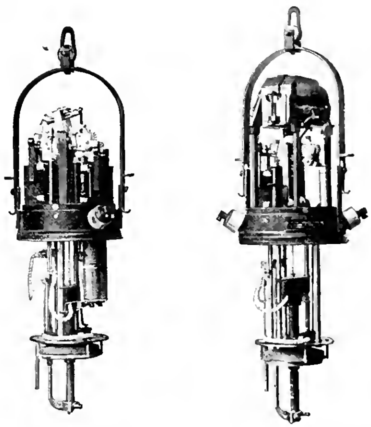
FIG. 51—EARLY LONG BURNING FLAME CARBON ARC LAMP

Many different forms of the flame carbon lamp were developed in Europe and were introduced to a limited extent in this country, practically all having the inclined V carbons, which necessitated a focusing mechanism which would feed both carbons at the same rate. The mechanism of these lamps was ingenious, and in some cases quite complicated, including a reversion to the earlier forms of gravity operated, clock-fed mechanisms, while in one form the mechanism was actuated by a small motor in the top of the lamp. Excessive maintenance charges prevented the general introduction of this type of lamp in this country.



Nearly all of the early lamps carried with their remarkable improvements at least two troubles which were

new to arc lamp users. These were due to the presence in the carbon of the relatively infusible, non-conducting oxides which were added to increase the luminosity of the arc. The consumption of the carbons resulted in fusing these compounds, which ran down the sides of



FIGS. 53 and 54—MECHANISM OF CONSTANT-CURRENT AND CONSTANT POTENTIAL ALTERNATING-CURRENT LONG BURNING FLAME CARBON ARC LAMP

the carbons, forming glassy insulating beads which prevented the carbons from coming into contact when the lamp was extinguished, and thus preventing them from restarting without attention. The second problem introduced by the new carbons was the disposal of the volatilized mineral matter. If this were allowed to

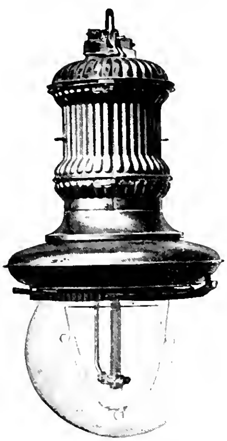


FIG. 55

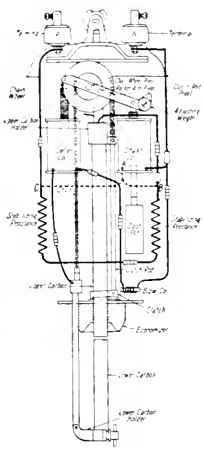


FIG. 56

Fig. 55—Modern Westinghouse long-life flame carbon arc lamp
Fig. 56—Schematic diagram of arc lamp mechanism and connections.

escape freely (as it frequently did) the dense white choking fumes turned its strongest advocate against the lamp. If an attempt were made to hold it within the lamp it rapidly settled upon the globe, absorbing so much of the light that the boasted efficiency was lost. It was soon discovered that a part of the soot could be condensed by causing the gases from the arc to pass over a cool surface, with the result that a metal chamber was eventually provided through which the gases were passed before escaping to the outside air. This reduced the trouble to a bearable degree, but its presence was responsible for the next step in flame carbon development. This was the so-called regenerative lamp placed upon the American market by the Adams-Bagnall Company.

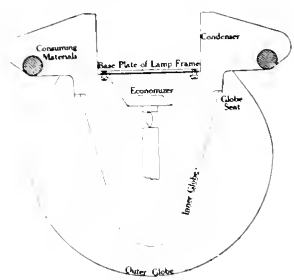


FIG. 57—DIAGRAM OF GLOBE, ARC CHAMBER AND CONDENSER

The regenerative lamp was based on the theory, proven by events to be more ingenious than practical, that if the space above the arc were connected with the space below the arc by a metal passage, a portion of the soot would be condensed by the tubes, the globe would stay clean, and a portion of the soot and gases would be used again and again. This development in turn gave place to the enclosed flame carbon arc lamp, which is at present the most efficient and economical lamp available.

The enclosed flame arc lamp, like all of its predecessors, is the result of the combined efforts of many men, but it is probable that Tito L. Carbone, of France, has contributed more largely than any other man to its development. Carbone found that the soot, when present in large quantities, would deposit on the surfaces with which it first came into contact, but that when the amount of soot in the circulating gases had been reduced by allowing a portion to deposit out, the remainder

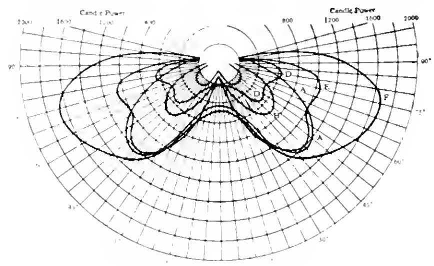


FIG. 58—ILLUMINATION CURVES OF ARC LAMPS

Curve	Lamp	Amperes	Terminal Volts	Arc Volts	Power-Factor	Terminal Watts	Mean Lower Hemispherical Candlepower	Mean Lower Hemispherical Candlepower Per Watt	Watts per Mean Lower Hemispherical Candlepower	Arc Length, In.
A	Direct Current, Open Arc	9.6	50	47		480	813	1.70	0.59	1/8
B	Direct Current, Enclosed Arc	6.6	75	71		495	482	1.03	0.97	3/8
C	A. C. Enclosed Arc	6.6	76	72	82	411	240	0.565	1.77	3/8
D	D. C. Metallic Flame Arc	4.0	68	66		272	495	1.82	0.55	1/2
E	D. C. Metallic Flame Arc	6.6	68	66		450	980	2.18	0.459	1/2
F	A. C. Flame Carbon (White) Arc	10.0	53	47	84	445	1400	3.12	0.317	3/4

would not readily condense on a hot surface. To take advantage of these principles he provided the flame carbon lamp with a flat, disc-shaped metal chamber, as shown in Fig. 50, and so placed on the arc that the

heated gases in rising upward passed into this "condensing chamber." He then provided a surrounding globe for the arc, so shaped that the portion adjacent to the arc, and through which the useful light passed, was kept very warm, while the lower portion of the globe was allowed to become somewhat cooler. The construction whereby this was accomplished is shown in Figs. 50 and 51, which also illustrates one of the early commercial forms in which this lamp was placed upon the market. The lamp is interesting as illustrating a reversion to the clockwork feed, as shown in Figs. 52, 53 and 54.

It was soon found that various detailed improvements could be made in the Carbone type of lamp, and the next development (about 1911) was the general type of lamp shown in Figs. 55 and 56. In this lamp one of the distinctive advances is the globe enclosing the arc, which is maintained at the proper temperature by surrounding it with an outer globe to shield it from air currents. The result is a greatly reduced deposit of soot on the inner globe, resulting in a much higher light efficiency. Since in this lamp the arc is carefully enclosed to prevent the access of air, the life of the carbons is long, in some cases being 130 hours per trim. In order to maintain the arc in the same position, a focusing mechanism is used, thus insuring that the arc will always be so located that the useful light can pass out through the soot-free portion of the inner globe. The general principles of the ventilation of the lamp are shown in Fig. 57. It was found that the proper design of the devices for disposing of the soot, together with rapid progress by both American and European carbon manufacturers, resulted in a very material reduction of all troubles due to the presence of the mineral material, so that today trouble of this kind may be considered a thing of the past.

FIG. 59—ORNAMENTAL POST TYPE FRAME CARBON ARC LAMP

It is interesting to trace in this modern lamp the influence of earlier types in the course of development. The regulating magnets, the chain wheel support, the ring carbon clutch for holding and feeding the carbons, the economizer and, in fact, all of the essential details, have proven reliable during the development in the past.

The development of the arc lamp as an illuminating agent is shown by the comparative curves of Fig. 58. A comparison of these curves shows that the change from the open carbon arc to the enclosed carbon arc was a distinct downward step as far as light-giving characteristics are concerned, although justified, as previously explained, by economic considerations. The metallic flame lamp restored the arc lamp to about its original status as a source of illumination, but with much improved efficiency, while the flame carbon lamp marks a distinctive step in advance from the standpoint of both illumination and efficiency.

Arc lamp design has been controlled by many forces. Not only has it been true that scientific and engineering progress has forced the development, and the growth of other light units driven it forward, but political and aesthetic conditions have contributed to the progress. Thus we find that, as the movement for civic improvement has advanced and municipalities have demanded more and better light, the demand has been met by lamp designers. As the larger communities have demanded a more ornamental unit, more in keeping with the requirements of the art commissions, which play no small part today in city planning, new types have been developed. One result of the growth of interest in an ornamental lamp has been the development of the inverted post type lamp shown in Fig. 59. This lamp is provided with substantially the same mechanism as the pendant type, but is arranged for mounting on pillars or brackets with overhead support or external connections, thus lending itself well to various architectural requirements. A similar lamp for pillar mounting is shown in Fig. 60.

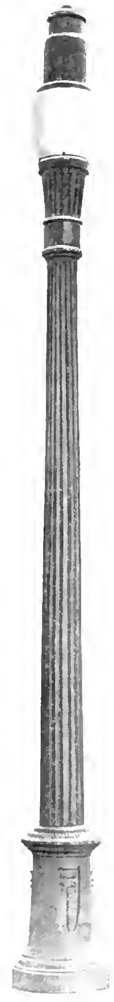


FIG. 60—PILLAR FLAME CARBON ARC LAMP FOR BOULEVARD OR PARK LIGHTING

The development of the arc lamp has been characterized by more activity, more radical innovations, and the way has been strewn with more relics than almost any other type of electrical apparatus. At some periods development has been retarded for decades by the lack of a necessary link in the complete system or commercial or financial conditions, while at other periods progress has been made with rapid strides.

The arc lamp, more than any other piece of electrical apparatus, is very dependent on allied branches of engineering. The carbon industry, the manufacture of porcelain, of glass, of alloys of all kinds and the production of various chemicals, all have had a controlling influence on the development of the arc lamp. In spite of the many factors which require consideration, the arc lamp has become a very important piece of electrical apparatus, and there is reason to expect continued development in the future.

Operating Experiences on the Erie R. R.

SOME NOTES ON THE OVERHEAD CONSTRUCTION OF THE ROCHESTER DIVISION

R. C. Thurston

ONE of the first instances in which a steam railroad electrified one of its own feeder lines was the 34 mile branch of the Erie Railroad between Mount Morris and Rochester, New York. When this installation was installed in 1906 the art of designing the overhead contact system for high-voltage work was in its infancy and many things were thought proper then that would not be considered now. The defects did not develop at once, but did from time to time. One of the first was the electrical breakdown of some composition insulators used as dead ends. Mechanically the dead ends were perfect, but after some months of service weather cracks developed which would allow water to penetrate the interior of the insulator. It was no unusual thing for two to four to become defective at the same time. This was remedied by removing all insulators of this type and installing porcelain, from which there has been but little trouble, due probably to the fact that, wherever possible, two 20 000 volt insulators were put in series in place of one composition insulator.

Trouble was also experienced due to high wind, which is quite prevalent at certain seasons; the pressure of the pantograph against the wire (about eight pounds) was not enough to cause a shoe to hit the crossarm, but a west wind striking a north or south bound car would cause it to roll toward the east. The wind also would have a tendency to blow the wire in the same direction. The two conditions combined would allow the pantograph to rise too high so that it would strike the crossarm, with consequent delay due to a crippled car and sometimes to a grounded line. Originally there were no steady braces on the line, except on curves, and it was thought that with the addition of one steady brace on every third pole (one every 360 feet) on tangents the line would be secure from like trouble in the future. But it was found that in the summer, when the line was slack due to expansion, the same trouble developed. It was then decided to brace the line at every pole, which was done. It might not be expedient to do this on future work, as the additional insulators make additional points of possible breakdown.

This 11 000 volt line is of single catenary construction, 7/16 inch steel stranded messenger wire and 3/0 hard-drawn copper contact wire. The spacing rods are

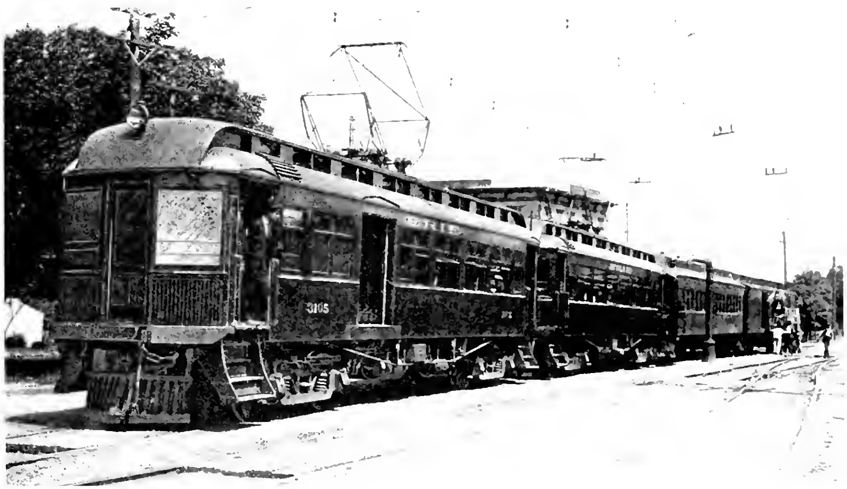


FIG. 1—MULTIPLE-UNIT TRAIN ON THE ERIE RAILROAD

of 5/8 inch round iron, with trolley and messenger clamps of twin pieces of cast iron with cups and lock nuts. The longest spacing rod measures 15.5 inches from the center of the messenger to the groove of the trolley wire, weighs four pounds and is within five feet of the supporting insulator on the crossarm. After three or four years of service the wire commenced to break, usually at the longest hanger. This was due, it was thought, to the weight and the fact that temperature did not affect the copper and steel equally, so that the spacing rod would tilt to form a high spot in the contact wire, which became crystallized and finally broke from the hammer blows of the shoe. The trouble increased to such a proportion that it was decided to install a steel contact wire directly under and attached to the original copper by clamps. As all of this work had to be done at night, it was necessary that care should be taken to foresee and prepare for the work so that there

would be as little delay as possible, as there was usually only seven or eight hours per night when the line could be worked upon, and part of that time might be taken to allow freight trains to pass. This time was divided from 9:00 P. M. to 10:10 P. M., then from 12:10 A. M. to 6:00 or 6:30 A. M. No. 000 grooved steel contact wire was used of 13 percent conductivity, and new spacing clips were installed every ten feet, midway between the old spacing rods. The clips were composed of two castings with one one-half inch carriage bolt and a hexagonal nut and lock washer. A bolt was used instead of the two screws originally proposed, to save time, as the work had to be done in poor light and much time might be lost in searching for the screw slots. Crank socket wrenches were provided, with the result that a clamp could be installed and tightened while the work train was moving.

The work was started the first night at 12:30 A. M., with a work train consisting of an engine, a flat car upon which were mounted the spools of wire, a pole for raising the wire, and spare tools, and a tower car with a deck about 30 feet long, a train crew and five workmen, including the leader. A permanent connection was made between the new steel wire and the old wire, then the new was run out and hooked to the messenger wire with "S" hooks. Two pulls were made one-half mile apart and the free end of the wire was clamped securely to the messenger wire. The clipping in was then done, and the first mile was three-quarters completed the first night. The second night two miles were run out and hooked up so that only clipping in should be done during the short space of time allowed before midnight.

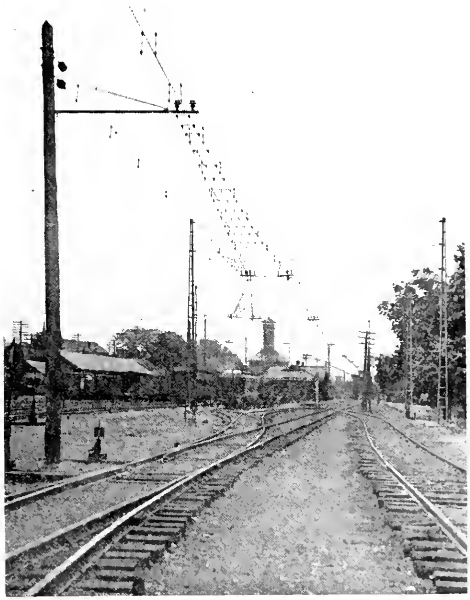


FIG. 2—TYPICAL CATENARY CONSTRUCTION ON THE ERIE ELECTRIFICATION

It was estimated that this work would cost about $12 000 for the 34 miles of main track and about three miles of sidings and yards, the cost to cover renewals of deflectors or their adjustment to the level of the new wire. The actual cost was as follows:—

Material	$ 8170.24
Labor	1036.60
Work Train and Crew	1818.40
Supervising—Engineering	301.12
	$11 332.42

The new wire has cured the trouble of broken wire, but has decreased the life of pantograph shoes to about 2500 miles.

A slight mistake was made in the design of the spacing clips for clamping the new steel trolley wire, inasmuch as it was expected that the clips would clamp the new wire securely and be free to slide on the old copper wire, so that there would be the automatic adjustment necessary to temperature variation. But the bolt allowed the clamps to be pulled up too far, so that quite often both wires would be clamped tight and thus prevent the adjustment. This could be taken care of in any future work.

Flashing in Direct-Current Machines*

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ONE of the limits in commutating machinery is flashing. Different kinds of flashes may arise from radically different causes, some of which may be normally present in the machine, while others may be of an accidental nature. Whatever the initial cause, the flash itself means vaporized conducting material. If the heat developed by or in this vapor arc is sufficient to vaporize more conducting material, then the arc or flash will grow or continue. Thus, true flashing should be associated with vaporization and, in many cases, in order to get at the initial cause of flashing, it is only necessary to find the initial cause of vaporization.

ARCS BETWEEN ADJACENT COMMUTATOR BARS

A not uncommon condition on commutators in operation is a belt of incandescent material around the commutator, usually known as "ring fire." This is really

*Based on a paper read before the American Institute of Electrical Engineers, Sept., 1915.

incandescent material between adjacent bars, such as carbon or graphite, scraped off the brush faces, usually by the mica between bars. These particles are conducting and, if there is sufficient voltage and current to bring them up to incandescence, this shows as a streak of fire around the commutator. In many cases, by its different intensities around the commutator, this ring fire shows the density of the field flux, or the e.m.f. distribution around the machine. It is practically zero in the commutating zone and shows plainly under the main field. In loaded machines, this often indicates roughly the flux distortion.

With undercut commutators ring fire is also observable at times, due to conducting particles in the slots between bars. Usually such particles consist of carbon or graphite, but particles of copper may also be present. Also, oil or grease, mixed with carbon, will carbonize, and thus add to the ring fire. Often when a commutator is rubbed with an oiled cloth or wiper, ring fire will show very plainly, and then gradually die down. The burning oil exaggerates the action, and also, the oil itself may enable a conducting coating to adhere to the mica edges, thus starting the action, which disappears when the oil film is burned away. However, when the oil can penetrate the mica, the incandescence may continue in spots, the mica being burned away. This is the action usually called "pitting," which is almost invariably caused by conducting material in the mica, such as carbonized oil, carbonized binding material, copper and carbon particles.

Ring fire is not always a direct function of the voltage between bars, although, under exactly equivalent conditions of speed, grade of brushes, etc., it is closely allied with voltage conditions. In high voltage machines, hard high-resistance brushes are used, which tend to give off the least carbon in the form of particles. In low voltage machines, soft, low-resistance brushes, containing a good percentage of graphite, are common, and these naturally tend to coat the mica to a greater extent. Under extreme conditions, ring fire may become so intense locally that there is an actual arc formed between two adjacent bars, due to vaporization of the copper. This may show in the form of minute copper beads at the edge of the bar. In extreme cases conical-shaped cavities or holes may be burned in the copper. In such cases the arc is usually explosive, resembling somewhat a small "buck-over." Part of the missing copper has been vaporized by the arc, while part may have become so softened or fused that it is thrown off by centrifugal force. Experience shows that sometimes these explosives arcs grow into general flashes, while at other times they are purely local.

Extended studies have been made of such arcs to determine the conditions which produce them. Numerous tests have also been made under the writer's supervisions, the results of which are given below.

It was determined first that explosive arcs between adjacent bars were dependent upon fairly high voltage between bars. It was also found that a voltage between bars which would produce arcs in one case would not do so in another. Apparently there were other controlling conditions. It developed that the resistance of the armature winding between two adjacent bars has much to do with the arc. Apparently an excessive current is necessary to melt a small chunk out of a mass of good heat-conducting material like copper; and also, a certain amount of time is required to bring it up to the melting point. Therefore, both time and current are involved, as well as voltage.

The commutator of a high-speed, 20 kw machine was sprinkled with iron filings, fine dust, etc., during several days' operation under various conditions of load, field distortion, etc. Such dust, whether conducting or not, apparently would not cause arcing between bars. Graphite was finally applied with a special "wiper," and with this small arcs or flashes could be produced at 50 to 60 volts maximum between commutator bars. It soon became evident that this was too small a machine from which to draw conclusions. Then other larger generators were tested. A 200 kw, 250 volt, slow-speed generator was speeded up to about double speed, in order to obtain sufficiently high e.m.f. between commutator bars. With a clean commutator nothing was obtained at 40 volts maximum per bar. The commutator was then wiped with a piece of oily waste which had been used to wipe off other commutators. Arcs then occurred repeatedly between commutator bars, although all such arcs were confined to adjacent bars and there were no actual flashovers. Moreover, the arcs always appeared to start about midway between neutral points, and lasted only until the next neutral point was reached. Quite large pits were burned in the bars next to the mica, some of these being possibly one-fourth inch in width and one-sixteenth inch deep. This indicated excessively large currents. These arcs would develop at about 32 to 34 volts between bars, and they were explosive above 35 volts.

Still larger machines were tested at various speeds, voltages, etc. It was found that, as a rule, the larger the machine, or rather, the lower the resistance of the armature winding per bar, the lower would be the voltage at which serious arcing would develop. In these tests it was found that graphite mixed with grease gave the most sensitive arcing conditions.

No arcing between bars developed at less than 28 volts maximum, while 30 volts was approximately the limit on many machines. However, the results varied with the speed. Apparently it took a certain time to raise the incandescent material to the arcing point and to build up a big arc. Therefore, the duration of the possible arcing period appeared to be involved. If this were so, then a higher voltage limit for a shorter time should be possible with the same arcing tendency. Also, if this were the case, then with 30 volts maximum, for instance, with an undistorted field flux, the arcing should be the same as with a somewhat higher voltage with a highly distorted narrow peaked field. In other words, the limiting voltage between bars on a loaded ma-

chine might be somewhat higher than on an unloaded machine. This was actually found to be the case, the difference being from 10 to 15 percent, depending upon various limiting conditions such as the actual period within which the arc could build up to a destructive point, etc.

One interesting case developed which apparently illustrated the effects of lengthening or shortening the period during which the arc could occur. A high-speed, 600 volt generator was at about 60 percent above normal speed. Even at normal speed this was a rather high frequency machine, so that the period of time for a commutator bar to pass from neutral point to neutral point was very short. At the highest speed the graphite grease was used liberally on the commutator, but without causing arcing, even when the voltage was raised considerably higher than usually required for producing arcs between bars in other machines of similar size. Neither was there much ring fire at the highest speed with normal voltage. Finally, after an application of graphite, without forming arcs or unusual ring fire, the speed was reduced gradually with normal voltage maintained. The ring fire increased with decrease in speed, until at about normal speed it was so excessive that the onlookers expected an explosion of some sort. However, the voltage was now below the normal arcing point and nothing happened. At still lower speed, but with reduced voltage on account of saturation, the ring fire gradually decreased. Apparently at the very high speeds the time was too short for the ring fire to reach its maximum; while with reduction in speed, even with somewhat reduced voltage, the ring fire increased to a maximum and then decreased. This test was continued sufficiently to be sure that it was not an accidental case. Only a certain combination of speed, frequency, voltage, etc., could develop this peculiar condition, and it was purely by accident that this combination was obtained, for the result was not foreseen in selecting the particular machine used.

A summation of these and other tests led to the conclusion that there were definite limits to the maximum voltage per bar beyond which it was not safe to go. These limits, however, involved such a number of conditions that no fixed rule could be established. The grades and materials of the brushes, the thickness of the mica, flux distortion from overloads, etc., must be taken into account.

The general conclusions were that with 1/32 inch mica large current machines would very rarely flash with 28 volts *maximum* between bars; while with moderate capacities 30 volts is about the lower limit; and with still smaller machines, 100 kw for example, this might be as high as 33 to 35 volts, the limit rising to 50 or 60 volts with very small machines. Of course, the brush conditions have something to do with the above limits, and exceptions to these figures will be found in actual practice. Many machines are in daily service which are subject to more or less ring fire, but which have never developed trouble of this sort, and doubtless never will. Apparently ring fire is not harmful in itself; it is only where it starts some other trouble that it may be considered as actually objectionable.

The above limiting figures are interesting when compared with the voltages necessary to establish arcs in general. Usually an alternating arc through air will not maintain itself at less than some limiting voltage such as 20 to 25 volts, corresponding to peak values of 28 to 35 volts. Moreover, an arc formed between the edges of two insulated bodies, such as adjacent commutator bars, will naturally tend to rupture itself, due to the shape of its path. Furthermore, the resistance and reactance of the short-circuited path, while comparatively low in large machines, will tend to limit the voltage which maintains the arc. In small machines with relatively high internal drops in the short-circuited coils, the current will not reach a commutator vaporizing value unless the initial voltage between bars is comparatively high, and usually the explosive actions are relatively small and, in many cases, no serious arcs will develop at all. Obviously, the less the local current can increase in the case of short circuits between adjacent bars, the higher the voltage between bars can be without danger. In machines having *inherent constant-current characteristics,* very high voltages between adjacent commutator bars are possible without serious flashing or burning.

In view of the fact that small arcs of a non-explosive sort may form at voltages considerably lower than the limits given, it should be considered whether such small arcs can cause any trouble if no other live parts of the machine are in close proximity. One case should be considered, namely, that of other commutator bars adjacent to the arc. When conducting vapor is formed by the first minute arc, this vapor in spreading out may bridge across a number of commutator bars having a much higher total difference of potential across them than that which caused the initial arc. Assume, for instance, a very crowded design of high-voltage commutator. In some cases, in order to use high rotative speeds, without unduly high commutator peripheral speed, the commutator bars are made very thin and the voltage per bar very high, possibly up almost to the limit. Assuming five bars per inch and a maximum of 25 volts per bar, then there is an e.m.f. of 125 volts *per inch* circumference of the commutator. In such case a small arc between two bars may result in bridging across a comparatively high voltage through the resulting copper vapor. Therefore, when considering the possible harmful effects of minute arcs, the voltage per inch of commutator should be taken into consideration. The writer observed one high voltage commutator which flashed viciously at times, apparently without "provocation." The only explanation he could find was that the vapor from little arcs resulting from ring fire was sufficient to spread all over the commutator, the bars being very thin and the voltage per bar very high. However, difficulties from this cause have not yet become serious, probably because no one has yet carried such constructions to the extreme in practical work.

High voltage between commutator bars may result in flashing due to other than normal operating conditions. Excessive overloads may give such high voltages per armature coil or per commutator bar, immediately under the brush, that the terrific current rush will develop conducting vapors under the brush, which appear immediately in front of the brushes, as such vapors naturally are carried forward by rotation of the commutator. This short-circuit condition under the brush has already been referred to when treating of commutation limits. It was shown that an inherent short-circuit voltage of 4 to 4.5 volts is permissible in good practice. Immediately under the commutating pole this voltage is practically neutralized by the commutating pole field, but immediately ahead or behind the pole it is not neutralized usually, except to the extent of the commutating pole flux fringe. Thus the resultant voltage between two bars a little distance ahead of the brush is liable to be considerably higher than under the brush. Assuming, for instance, 3.5 volts per bar, due to cutting the resultant field just ahead of the brush, then with ten times full-load current, for example, there would be 35 volts between bars, and this is liable to be accompanied by highly conducting vapor formed by the excessive current at the brush contact, this vapor being carried forward by rotation of the commutator. Here are the conditions for a flash, which may or may not bridge across to some other live part. If the current rush is not too great this flash will usually appear only as a momentary blaze just in front of the brush. In many cases, if this blaze or heavy arc were not allowed to come in contact with, or bridge between, any parts having high difference of potential, it would not be particularly harmful. In case of "dead short-circuiting" of large moderately high-voltage machines where the current can rise to 25 or 30 times normal, it is astonishing how large such arcs or flashes may become, and to what distances they will reach. The conducting vapor may be deflected by magnetic action and by air drafts. Shields or partitions will sometimes produce unexpected results not necessarily beneficial. Unless such shields actually touch the commutator face so that conducting vapor cannot pass underneath them, the vapor that does pass underneath may produce just as harmful results as if the shields were not used.

From the preceding considerations it would appear that a compensated direct-current machine should have some advantages over the straight commutating-pole type in case of a severe short-circuit. With the lesser saturation in the commutating pole circuit due to the lower leakage, the apparent armature short-circuit e.m.f. will usually be better neutralized under extreme load conditions, and thus there will be lower local currents in the brush contacts. In addition, the armature flux will be practically as well neutralized behind and ahead of the brush as it is under the brush, so that, with ten times current as in the former example, there may be only a low e.m.f. per bar ahead of the brush, instead of the 35 volts for the former case. Obviously, the cause of the initial flashing, and the tendency to continue it ahead of the brush, will be materially reduced. The compensating winding is therefore particularly advantageous in very high voltage generators, in which the bars are usually very thin and the maximum volts per bar are high.

There is a prevailing opinion that when a circuit breaker opens on heavy overload or a short-circuit, flashing is liable to follow from such interruption of the current. In some cases this may be true. However, when a circuit breaker opens on a short-circuit it is difficult for the observer to say whether both the opening of the breaker and the flash are due to the excessive momentary current, or one is consequent to the other. The short-circuit, if severe, will most certainly cause more or less of a flash at the brush contacts, and if this flash is carried around the commutator, or bridges across two points of widely different potentials, then it is liable to continue after the circuit breaker opens, and thus give the impression that the flashing followed the interruption of the circuit. In railway and in mine work in particular, a great many flashes which are credited to overloads are primarily caused by partial short-circuits on the system, or "arcing shorts," which are extinguished as soon as the circuit is opened. Such a partial short-circuit, however, may be sufficient to open the generator circuit and to cause a flash at the same time. Not infrequently such flashes are simply credited to opening of the circuit breakers.

There are other conditions where a flash is liable to result directly from opening the circuit breaker on heavy overload. If the apparent short-circuit e.m.f. per brush on heavy overload is from 25 to 35 volts, and if the armature magnetomotive force is interrupted suddenly, with a correspondingly rapid reduction in the armature flux, while the commutating field flux does not die down at an equally rapid rate, then momentarily there will be an actual short-circuit voltage of a considerable amount under the brushes which may be sufficient to circulate large enough local currents to start flashing. With commutating pole machines this condition may result from the use of solid poles and solid field yokes. Laminated commutating poles are sometimes very much of an improvement. However, the yokes of practically all direct-current machines are of solid material, and thus tend to give sluggishness in flux changes. The above explains why non-inductive shunts, or any closed circuits whatever, are usually objectionable on commutating poles or their windings. In non-commutating pole machines, where the brushes are liable to be shifted under the main field magnetic fringe in order to commutate heavy loads, flashing sometimes results when such heavy overload is interrupted. Also, if the rupture of the current is very sudden, there will be an inductive "kick" from the collapse of the armature magnetic field; this rise in voltage sometimes is sufficient to start a flash, especially in those cases where flashing limits are already almost reached.

In synchronous converters, the conditions are materially different from direct-current generators when

the load is suddenly broken. In such machines the flash is liable to follow the opening of the circuit breaker if a heavy overload is interrupted. This is possibly more pronounced in the commutating pole machine than in the non-commutating pole type. In a commutating pole converter the commutating pole magnetomotive force is considerably larger than the resultant armature magnetomotive force under normal operating conditions, but is much smaller than the armature magnetomotive force considered as a straight direct-current or alternating-current machine. Normally the commutating pole establishes a commutating field or flux in the proper direction in the armature. However if, for any reason, the converter becomes a motor or a generator, even momentarily, the increased magnetomotive force of the armature may greatly exceed that of the commutating pole, so that the commutating pole flux will be greatly increased, or it may be greatly reduced, or even reversed, depending upon which armature magnetomotive force predominates.

The above is what happens when a synchronous converter hunts, and under the accompanying condition of variable armature magnetomotive force the commutating pole converter, with iron directly over the commutating zone, is liable to show greater variations in the flux in the commutating zone than is the case in the non-commutating pole converter. Experience has shown that when a synchronous converter carrying a heavy overload has its direct-current circuit suddenly interrupted it is liable to hunt considerably for a very short period. This hunting means wide variations in the commutating pole flux with corresponding sparking tendencies. For a "swing" or two this sparking may be so bad as to develop into a flash. Thus the flash follows the interruption of the circuit. Curiously, the most effective remedy for this condition is one which has proven most objectionable in direct-current machines, namely, a low-resistance closed electric circuit surrounding the commutating pole. The primary object of this remedy is not to form a closed circuit around the commutating field, but to obtain a more effective damper in order to minimize hunting.

In direct-current railway motors, flashing at the commutator is not an uncommon occurrence. One common cause is jolting the brushes away from the commutator. The carbon breaks contact with the copper, forming an arc which is carried around. Another prolific source of flashing is the opening and closing of the motor circuit in passing over a gap or dead section in a trolley circuit. Here the motor current is entirely interrupted and, after a short interval, it comes on again, without any resistance in circuit except that of the motor itself. If the current rush at the first moment of closing is not too large, and if the armature and field magnetic fluxes build up at the same rate, there is usually but small danger of a flash. The rapidly changing field flux, however, generates heavy currents under the brushes, thus tending toward flashing. The reactance of the motors, especially of the field windings, limits the first current rush to a great extent. According to this, closed secondary circuits of low resistance around either the main poles or the commutating poles should be objectionable, and experience bears this out.

AVERAGE E.M.F. AND "FIELD FORM"

A rather common practice has been to specify the average volts per bar in a given machine. The limit is really fixed by the maximum volts per bar, and there is no fixed relation between the average and the maximum volts per bar. The ratio between these two voltages is dependent upon the field flux distribution, that is, the "field form." In well-proportioned modern machines the average e.m.f. per bar is about 70 percent of the maximum at no load, and about 55 to 60 percent with heavy load. This means that about 15 volts per bar, average, is the maximum permissible in large machines with considerable field distortion if a maximum of 28 volts per bar is not to be exceeded. On this basis a 660 volt machine should have not less than 40 commutator bars per pole. However, this is with considerable field distortion. If this distortion is reduced or eliminated, the average volts can be considerably higher, as in machines with high saturation in the pole faces, pole horns and armature teeth, or with compensated fields. Synchronous converters are practically self-compensated and can, therefore, have higher limits than the above if the normal rated e.m.f. is never to be exceeded. However, in 600 volt converter work in particular, wide variations sometimes occur momentarily up to 700 to 750 volts, and such machines should have some margin for such voltage swings. The ordinary 600 volt direct-current generator also attains materially higher voltages at times, which should be taken into account in limiting the voltage per commutator bar and the total number of bars per pole.

Obviously, the fatter the field form, the nearer the average voltage can approach the maximum. With an 80 percent field form, instead of 70 percent, for instance, the number of bars per pole can be reduced directly as the polar percentage is increased; and 35 bars per pole with 80 percent would be as good as 40 bars with 70 percent, assuming the same percentage of field distortion in both cases.

Usually it is considered that the commutating conditions of a machine are practically the same with the same current, whether it be operated as a generator or motor. However, when it comes to flashing conditions, there is one very considerable difference. In the direct-current generator, the field flux distortion by the armature is such as to crowd the highest field density, and thus the highest volts per bar, away from the forward edge of the brushes. In the motor, the opposite is the case, and therefore there is a steeply rising field, and a corresponding e.m.f. distribution in front of the brushes. As the flash is carried in the direction of rotation it may be seen that, in this particular, the generator and motor are different.

Autotransformers

E. G Reed

An AUTOTRANSFORMER is a transformer with a single winding. This single winding, therefore, must perform the functions of both the primary and secondary elements of a two-winding transformer. For this reason it is to be expected that an autotransformer can be built with less material, and that its efficiency and regulation will be superior to a two-winding transformer of the same rating. The main

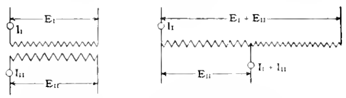


FIG. 1—TWO-WINDING TRANSFORMER, RECONNECTED TO FORM AUTOTRANSFORMER

objection to the use of the autotransformer, where it might otherwise be used to advantage, is the fact that the primary and secondary circuits are not electrically separated.

RELATION BETWEEN RATIO AND OUTPUT RATING

The output P_T of a transformer having E_I and I_I as primary voltage and current, and E_{II} and I_{II} as secondary voltage and current, is,—

$$P_T = E_I\, I_I = E_{II}\, I_{II}$$

This transformer may be connected as an autotransformer as shown in Fig. 1. In this case the output P_A becomes,—

$$P_A = E_{II}\,(I_I + I_{II})$$

Combining these two equations gives,—

$$P_A = P_T \left(\frac{E_I + E_{II}}{E_I}\right) \qquad (1)$$

This relation may be put into a more general form

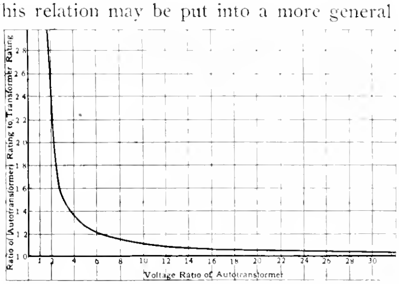


FIG. 2—RATING OF A TRANSFORMER WHEN CONNECTED AS AN AUTOTRANSFORMER

as follows:—Let the ratio of transformation of the autotransformer be R, then,—

$$R = \frac{E_I + E_{II}}{E_{II}}$$

Combining this with equation (1) gives,—

$$P_A = P_T \left(\frac{R}{R - 1}\right) \qquad (2)$$

In other words, the output of the autotransformer is equal to the output of the transformer times the voltage ratio of the autotransformer divided by the voltage ratio minus one.

Example—If a 10 k.v.a. transformer having voltages of 2200 to 440 volts be connected as an autotransformer having a ratio of 2640 to 440, the output of the autotransformer will be, from equation (2),—

$$P_A = 10 \; \frac{\frac{2640}{440}}{\frac{2640}{440} - 1} = 10 \times 1.2 = 12 \text{ k.v.a.}$$

The curve in Fig. 2 shows in a general way the increased rating of a two-winding transformer, when reconnected to form an autotransformer, for various voltage ratios of transformation of the autotransformer. It is apparent that the rating increases rapidly with decreasing ratios below five, and for ratios greater than ten is practically constant.

Since a two-winding transformer can be reconnected as an autotransformer and give an increased rating, it is evident that with the same rating an auto-

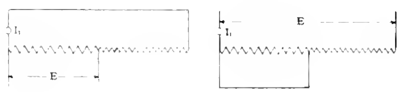


FIG. 3—MEASURING THE IMPEDANCE VOLTS OF AN AUTOTRANSFORMER

transformer can be built with less material. When the transformer windings are reconnected to form an autotransformer with a greater output rating, the current densities, and consequently the losses, remain the same, and since the output has increased, the efficiency is increased. Since the percentage copper loss is less, the regulation at high power-factors is evidently improved.

RELATION OF TRANSFORMER TO AUTOTRANSFORMER IMPEDANCE

The impedance of a two-winding transformer may be determined by short-circuiting the high-tension winding and impressing voltage on the low-tension winding; or by short-circuiting the low-tension winding and impressing voltage on the high-tension winding. If E be the voltage required to circulate full-load currents in the windings in either case and E_n be the normal voltage of the winding upon which the voltage E is impressed, by definition,—

$$Z_T = \frac{E}{E_n}$$

If I_n be the normal current in the circuit upon which voltage is impressed, this equation may be written,—

$$Z_T = \frac{E I_n}{E_n I_n}$$

In other words,—

$$Z_T = \frac{\textit{Volt-amperes taken on short-circuit}}{\textit{Rated volt-amperes of transformer}}$$

Similarly, the impedance of an autotransformer is,—

$$Z_A = \frac{\textit{Volt-amperes taken on short-circuit}}{\textit{Rated volt-amperes of autotransformer}} \quad \text{........(3)}$$

If EI_n be the volt-amperes taken on short-circuit by a two-winding transformer connected by either of the methods shown in Fig. 3, and E_nI_n is the normal output rating of the transformer, the impedance, as shown by equation (3), is,—

$$Z_A = \frac{E\,I_n}{(E_n\,I_n)\,\dfrac{R}{R-1}} \quad \text{..........(4)}$$

the output rating of the transformer being taken from equation (2) as being times $\left(\frac{R}{R-1}\right)$ the rating of the windings connected as a transformer, or,—

$$Z_A = \frac{E}{E_n} \times \frac{R-1}{R}$$

Now $\frac{E}{E_n}$ is the impedance of the windings connected as a transformer, therefore,—

$$Z_A = Z_T\,\frac{R-1}{R} \quad \text{..........(5)}$$

It is evident from the preceding that the lower impedance of the windings connected as an autotransformer is due to the greater output rating of the autotransformer as compared to the output rating of the windings connected as a transformer.

The impedance of an autotransformer may be measured directly by either of the connections shown in Fig. 3, and the above demonstration is given only to show the relation between the impedance of the two windings connected as a transformer and as an autotransformer.

Example—If a 10 k.v.a. transformer having voltages of 2200 to 440 volts has an impedance of three percent, its percent impedance connected as a 12 k.v.a. autotransformer will be,—

$$Z_A = 3 \times \frac{\frac{2640}{440} - 1}{\frac{2640}{440}} = 3 \times 0.83 = 2.5 \text{ percent.}$$

Since both the percentage copper loss and reactance is less for the windings connected as an autotransformer, the regulation will be better at all power-factors.

ENGINEERING NOTES

Silicon Steel

Transformer laminations are often made from silicon steel instead of soft iron. When soft iron was used considerable trouble was experienced from aging of the iron; that is, after the transformer had been in service awhile the iron losses increased. Silicon steel was found to be free from this defect and has been applied to transformer cores on this account. In spite of low iron losses a silicon steel transformer requires a higher magnetizing current than a soft iron ore, due to the fact that the permeability of silicon steel is lower than soft iron. This magnetizing current, however, does not represent any material power loss in the transformer.

Silicon steel is not generally used in rotating machines, partly because it is brittle and crystallizes easily if subjected to vibration, and because it also becomes saturated at a lower density. This is a detriment in those types of apparatus where the flux densities run high, for this would require a very considerable increase in magnetizing current. R. H. WILLARD

Ventilation of Shunt Field Coils

Shunt field coils are sub-divided to secure more nearly uniform temperature rise in all parts of the coils. Thick coils, which have no means of readily dissipating the heat developed inside, are liable to burn out even where the temperature rise on the outside of the coils may be entirely safe. On the other hand, thin coil sections not only ventilate well, but require less copper to give the same excitation within a specified temperature limit.

For a fixed value of excitation (ampere-turns) the permissible voltage drop or exciting voltage across the coils determines the size of conductor. The ampere-turns may be secured either by the product of high current and few turns or low current and many turns. For a selected size of conductor minimum weight corresponds to maximum current; that is, maximum I^2R per unit length. This I^2R can only be dissipated from the surface of the coil as heat; consequently, for a fixed temperature limit maximum ventilation per pound of conductor is an essential factor in the design.

To improve the ventilation recent practice in large units sub-divides the coils in two ways, viz., vertical section or concentric coils, and horizontal section or pancake coils, as shown in Figs. 1 and 2, respectively. The concentric type of coil offers a more direct path to the radial air currents thrown out from the armature, and as it is generally made in but two sections, as compared with three or more sections employed in the pancake coil, the labor of assembling the former is less. The pancake form is well suited for strap wound coils, where the ventilation is secured by means of end-bells which deflect the air currents from the rotor through the field. R. H. TABER

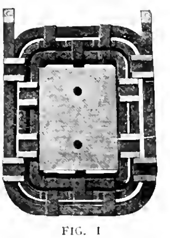


FIG. 1

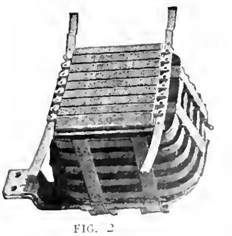


FIG. 2

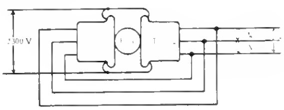
THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1274—Parallel Connection of Single-Phase Transformers—Fig. 1274(a) shows a diagram of a transformer connection about which there is some dispute. About three months ago one of two transformers connected in this way burned out. The transformer company claimed that a circulating current due to impedance was responsible for the damage. Still later they say that such a connection gives only half capacity. These transformers are identical and made to be connected in parallel. We have several sets so connected that have done their work for several years. Is there any real objection to this connection, which is very convenient on the pole? W. F. H. (IOWA)

If the transformers are identical, their operation should be entirely satisfactory when connected in parallel, as shown in Fig. 1274(a). If the transformers were



not identical in design and there were considerable difference in their impedances, there might possibly be enough circulating current to give trouble, but this would not be the case with duplicate designs. W. M. M.

1275—Would you consider $1.50 per horse-power year too high a sum to be charged against the repairs on a battery of four 500 horse-power boilers? F. G. F. (W. VA.)

For an average installation, a charge of $1.50 per horse-power for one year on four 500 horse-power boilers would seem to be below the average. It is difficult to advise a standard charge in this case, as it will vary greatly with the operating conditions and the size of the boilers, but it would seem, as far as may be determined from the question, that the rate of $1.50 might be considered very reasonable. O. H. B.

1276—Lighting Arresters to Prevent Flashover—Are lightning arresters ever connected to rotary converters to prevent flashover or to alleviate the effectiveness of a flashover? If so, where is connection made, what type arrester is recommended, and what setting is given for a 500 volt machine? V. C. D. (NEW YORK)

For the protection of rotary converters against flashover, electrolytic arresters have been used with considerable success. Inasmuch as these arresters are used on direct-current circuits without the series spark gap, which is commonly used on alternating-current circuits, there is no spark gap setting to be given. When the aluminum arrester is employed, one unit of two cells in series is usually installed for each converter of 500 kw or greater capacity. Other types of arresters, such as the magnetic blowout and circuit breaker types, which are commonly used on direct-current circuits, are not used for the protection of rotary converters against flashover, because of their limited discharge capacity, due to the use of a series resistance. If the principal cause of trouble is lightning, the arrester should be connected across the terminals of the machine, outside the field windings. Assuming negative grounded, the connection is made between the positive terminal and ground. If, however, the principal cause of trouble is surges from within the machine, the arrester should be connected directly across the armature terminals inside both the series and commutating field windings. This latter connection, of course, leaves the field windings unprotected against lightning, but gives greater protection against flashovers, due to dynamic current surges. There is also a very cheap and effective condenser unit of about one microfarad capacity which has recently been used instead of the aluminum cell arrester, owing to its indestructibility. There is not much definite information as to the actual benefit derived from such protection. It is not claimed that the severity of a flashover is reduced. It is merely believed that certain high-voltage conditions which are likely to occur at the rotary converter are by such means rendered less likely to result in a flashover. Q. A. B. and J. S. Y.

1277—Alternating-Current Arc for Cutting Metal—Can the alternating-current arc be used for cutting wrought iron, cast iron, brass and copper? What would be the minimum capacity single-phase generator required to cut material one inch thick, and also two inches thick? What voltage would be required? What would be the minimum capacity of a direct-current generator to do the same work, and what voltage would be required? P. G. L. (NEW JERSEY)

The alternating-current arc can be used for cutting wrought iron and steel with about the same degree of success as the direct-current arc, but with the added disadvantage of noise; the lower the frequency, the greater the noise. Neither of these processes compares with the oxy-acetylene or the oxy-hydrogen process in neatness of cut, the arc producing a very ragged edge. The arc process cannot be recommended at all for cutting either cast iron, brass or copper as a regular commercial process. About 600 amperes at 75 volts would be required for either one-inch or two-inch material, although cutting can be done with less or greater capacity, the rate of cutting varying accordingly. Different investigators give different rates of cutting, the speeds varying from one-half to one square inch per minute per 100 amperes used on medium thick material. C. B. A.

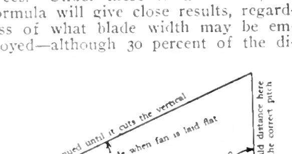
1278—Fan Blades—(a) How can I find the cubic capacity of a 28 inch flat blade, open type, exhaust fan, traveling 750 r.p.m.? (b) In what respect is the pitch considered in finding the air volume displaced per minute? (c) How can I find the horse-power required to drive a fan of known capacity? (d) Is the method of finding the pitch of a fan shown in Fig. 1278(a) correct? Assuming the theory right, would the air volume displaced be this area of the fan diameter (pitch travel) r.p.m.? T. K. (QUEBEC)

(a) and (b) are answered by No. 1239. (c) A formula for calculating the horse-power absorbed by fans is:—

$$Hp = K \times 10^{-11} \times D^5 \times R^3 \times \sqrt{B}\,(900 \tan\ \theta - 14)$$

D = maximum diameter in feet.
R = r.p.m.
B = number of blades.
θ = Angle blades make with plane of rotation.
K = 2 for a fan in free air — no surrounding tube.
= 1.4 for a fan mounted in a tube — free exit.
= 3.0 to 5.0 for a fan mounted in a tube — enclosed exit, increases with the number of blades

The formula is based on the assumption that the blades are flat, of constant angle and with slightly rounded corners at the tips. The angle should exceed 15 degrees, but should not exceed 60 degrees. Under these circumstances, the formula will give close results, regardless of what blade width may be employed—although 30 percent of the di-



ameter is general. If the blade angle is not known, it may be approximated from the following:—

$$\tan\ \theta = \frac{V}{1.05\ RD^3}$$

where V = cu. ft. per minute.

Catalogue values are usually not very accurate. (d) The method of finding the pitch is correct, but if the angle is constant, the tangent of the angle will vary inversely with the radius. Only in cases where the pitch is constant is the volume of air proportional to the area of the fan disc, times the pitch, times the r.p.m. Where the angle is constant and the pitch variable, it is better to use the formula given in No. 1239, where the effect of the varying pitch has been integrated. O. S. J.

FINANCIAL SECTION

ELECTRIC LIGHT AND POWER SECURITIES

Stability of income and safety of principal are the two cardinal factors which must be considered in every investment, and the securities which can best assure these two factors are the ones which any wise investor will, of course, prefer. Aside from government bonds and bonds issued by subordinate political districts, such as states, counties and municipalities, there is always some risk, and this risk is usually represented by the rate of income returned by the investment. Usually the safer the security the lower the rate of income returned to the holder. Of course, there are at times cases in which even governmental securities partake of a risk, but these are exceptional.

Whenever an investor is offered a security on which the rate of income is inordinately high, it is well for him carefully to scrutinize that security and not to purchase unless his investigation discloses that there are some exceptional circumstances surrounding it which account for the high rate of income which he would receive on such an investment. At one time many high-grade investment houses held that any bond returning over five percent on the investment could not be considered safe, but in recent years with the heavy demand for capital good bonds may be obtained which return six percent and even a higher rate of income on the money invested. The standard of income rate on gilt-edged bonds has been following a rather steady upward course for several years, which, of course, means a lower price for the securities which were issued at a time when the average income rate was lower than it is now.

This in turn means that should the holder of a bond purchased several years ago on a four percent basis now have to sell it on a five percent basis he would lose a part of his principal. But at the time when he purchased his bond he bought it on an income basis predicated on its being paid in full at maturity and, if his investment was wisely made, he will, in case the bond is held to maturity, receive the full amount which he originally was promised, in addition to his regular annual rate of income.

Statistics gathered at large expense by men engaged in the investment business show that, of public corporation bonds, none are so safe as to principal and income and none return a higher and more certain rate of income on the money invested than those of electric light and power companies. Furnishing a necessity, and the only necessity which is selling today at a lower rate than ten years ago, these electric light and power companies have had and will continue to have a steadily growing field from which to secure their revenues to pay the interest and dividends on their securities in the hands of investors. Free from labor troubles and comparatively free from attacks of political agitators, these companies are in an investment class by themselves. Statistics covering a long period of years prove that with average net annual earnings of $8 to each $100 of stocks and bonds outstanding, the light and power corporations of the country have had an annual risk of insolvency of but 37 cents to each $100 of capitalization. What this statement means may be shown by some statistics from other lines of industry.

The average investor considers that when he has placed his funds in a well-managed national bank he has them in as safe a place as may well be found. Yet the risk of insolvency in the national bank business is no smaller than in the light and power business. With average annual net earnings of around $8 on each $100 of capital invested, the insolvency risk in the large industrial corporations of the country has averaged $2.07 a year on each $100 of capital invested, while in the steam railroad business, with average annual net earnings of $4.25 to each $100 capital invested, the receivership risk of the steam railroads has been an average of $1.85 a year to each $100 of invested capital.

Today one-tenth of the mileage and one-sixth of the capitalization of the steam railroads of the country are in the hands of receivers, while at the same time there is not a large electric light and power company in receivership. While the net earnings of steam railroads have been, on the average, barely holding their own, the net earnings of the electric light and power companies of the country have been showing a progressive gain from year to year.

Because of the new fields constantly being found for electric current and its

FINANCIAL SECTION

steadily increasing utilization for light and power, the growth in earnings of these companies has been largely in advance of the growth in population of the communities served. One large group of light and power properties, serving communities in which the average annual growth of population was 3.06 percent, in the same period increased its earnings an average of 18 percent a year. In 1915 the light and power companies of the country made an average gain of seven percent in revenues, and this in a year in which the first six months was a period of declining earnings for all other classes of public corporations. In fact, there was not a month of the year in which the total earnings of the light and power companies of the country were not larger than they were for the corresponding period of the preceding year, the only effect of the depressed industrial condition of the country being a decline in the ratio of growth of revenues.

That these factors in the security behind the bonds of electric light and power companies are being realized is shown by the last report of the comptroller of the currency, that for the year ended June 30, 1915. There are 27 062 banks, national, state, savings, private and loan and trust companies, which once a year report to the comptroller of the currency their holdings of various classes of securities. For the year ended June 30, 1915, these 27 000 banks reported an increase of 5.32 percent in their aggregate holdings of securities of all kinds. The feature of the report was the great gain in holdings of public utility bonds, the majority of these held by the banks being light and power bonds. While there was a gain of 10.31 percent in state, county and municipal bonds, there was an increase of 13.70 percent in their holdings of public utility bonds, and the combined holdings of steam railroad bonds by banks of the country increased but 1.73 percent. One of the significant features of the report was that it was the savings banks of the country which showed the largest increase in their holdings of public utility bonds, increasing their holdings of these bonds by $55 000 000 in the year and decreasing their holdings of steam railroad bonds by $20 000 000.

The foregoing are but some of the factors which are causing the securities of electric light and power companies to become daily more popular with investors. These securities are now being made available to the modest investor, a number of high-class companies issuing their bonds in denominations as low as $100 face value, so that even the worker on a small salary may secure the advantage of a good rate of income with the highest degree of safety of both principal and interest. The men actively connected with the great development now going on in the light and power field, while realizing to the full the great increase in the business of the electric generating and distributing corporations, probably do not realize what this development is doing for the securities of the companies for which they are doing their untiring work. These men should realize that there are no safer investments for their surplus funds than the securities of the companies which they are helping to build up, and also that these securities are almost certain to advance greatly in value as they become better and better known to the great general investing public.

In the field of strictly investment securities, no other class has had so great an advance in average price in the last six months as the securities of the light and power companies. Six months ago the short-time notes of some of the best-known light and power companies were selling on an income basis of seven percent, but now they are practically unobtainable even at a much lower basis of income. The demand for light and power bonds has been such that the companies have been able to sell long-time bonds at a fair price and have used the proceeds to retire these short-time notes, which were issued at a time when all classes of long-time bonds were unsalable except at a large discount.

One feature of interest to the men actively engaged in the building up of the light and power industry is that because of the demand for these light and power bonds the electrical generating and distributing companies of the United States will this year put under way almost twice the new construction which they have done in any former year. The growth of popularity of light and power bonds has been such that the companies are now able to finance their requirements well ahead and thus meet the demand for electric energy which in many communities has outgrown the present generating and distributing facilities.

The earning record of the electric light and power companies since the outbreak of the European war and the consequent disturbance of financial and industrial affairs of the world has been one of the principal factors in calling the attention of the conservative investor to the merits of the light and power securities. Showing a gain even in the darkest months of the industrial situation of the country, the light and power companies at the same time have shown the most rapid recovery. While in February, 1915, there was an increase of but two percent in total revenues of the light and power industry of the country as compared with February, 1914, in December, 1915, light and power companies were reporting gains in revenues running as high as twenty-five percent over December, 1914. Coupled with this stability of earnings of the light and power companies since the outbreak of the European war has been a remarkable stability of prices of their bonds. A compilation of bonds issued by 96 representative light and power companies, representing a funded capitalization of more than $375 000 000, shows a loss of less than two points on an average in the quotations of these bonds in 1914, and since that time they have regained all this loss and are now selling higher on the average than previous to the outbreak of the war. The average price of these 96 bonds in 1915 was 92.23, which was 0.73 point above the low average price for the year and 1.77 points below the average high price. Fully eighty percent of the gain in the average price was made in the last quarter of the year. For the first three months of 1915 the average price was 91.66, for the second quarter 92.13, for the third quarter 92, and for the fourth quarter 93.13. For the first six months of 1915 the average price was 91.9, and for the second six months 92.56.

THE HOLDING COMPANY

Any discussion of the present-day light and power securities would be incomplete without a mention of those of public utility holding companies, the organizations which have made possible the great development of the electric railway, gas and electric light and power industries of today. It was these corporations which made possible the securing of the great amount of capital required to develop their individual operating units and also the assembling of the magnificently organized and directed corps of engineers, operators and new business men which have built up the operated properties to their present position as revenue-producing corporations.

It is not possible to much more than outline in such an article as this the full scope and work of the holding corporation idea as exemplified in its work in the light and power field, but by reason of the putting under one central control of diversified and separately located utility properties, of the ability by means of the large corporation to secure adequate amounts of capital at reasonable rates for even the smallest of the units of the organization, by spread-

FINANCIAL SECTION

ing the risk over a large number of properties and giving to each a system of management, which in the past only the largest corporations of the country were able to maintain, the holding company has brought the management, financing and earning qualities of light and power properties up to a remarkably efficient basis.

The investor should direct his attention to the securities of these holding companies, for in them he will find, where they have been properly organized and financed and have the proper management, almost an ideal form of security. Uniting in one organization almost all classes of utility properties, with the risk of physical damage or decreases in earnings to the properties as a whole brought to a minimum, their securities are steadily becoming more popular.

The public utility holding company must not be confused with the holding corporations which brought loss to many investors in the railroad field, for they are neither organized nor managed along similar lines. The utility holding corporation is utilized as a central organization for the financing and managing of many small operating units, and its greatest work comes in the fact that, by means of its large resources, it is able to bring to its smallest property the same efficient direction and economical financing that could be secured by the individually owned property in the largest city of the country.

AMERICAN LIGHT & TRACTION

American Light & Traction Company in 1915 received in income from operations of its subsidiary companies and from other sources $4 555 156, an increase of $746 000 over 1914. After providing for dividends on its preferred stock, which were earned more than five times over requirements, there was left $4 167 592 for the common stock, or 24.61 percent on the outstanding issue. American Light & Traction preferred sells at the highest price of any public utility 6 percent preferred stock, and at the same time the company pays the largest dividends on its common stock. In addition to regular cash dividends of 2.5 percent a quarter, it also pays quarterly dividends on its common stock of 2.5 percent in common stock, making 20 percent in dividends annually. As the common stock is now selling at about $375 a share these cash and stock dividends amount to approximately 50 percent a year on the par value of $100 a share. It has paid these dividends for the last five years, and men closely associated with the company say that with its present rate of gain in earnings it can continue to pay them indefinitely. In 1915 the subsidiaries of American Light & Traction increased their sales of electric energy by 4 201 410 kilowatt-hours, or 9.32 percent.

ELECTRIC ENERGY IN STEEL MAKING

Use of electric energy in steel making has grown to large proportions, and the expansion of the iron and steel business in Northern Ohio has resulted in large increase of business for several electric generating and distributing companies in that territory. At Alliance, Massillon and Warren several steel mills have been equipped with motor drive for their rolls, and a statement has been issued by the electric companies operating in these Northern Ohio towns showing how rapidly their sales of energy for power have increased in the last three years. In 1915, at Alliance, $31 956 of electric energy was sold for power, as compared with $22 611 in 1914 and $23 097 in 1913. At Warren sales of energy for power were $116 626 in 1915, as compared with $74 707 in 1914 and $73 284 in 1913. At Massillon sales for power were $77 320 in 1915, as compared with $30 651 in 1914 and $23 396 in 1913; while at Elyria the revenue from power sales was $80 220 in 1915, $53 839 in 1914 and $33 839 in 1913.

The prospects for 1916 are for largely increased sales of electric energy to the steel industry. The Trumbull Steel Company, of Warren, is planning an open-hearth steel mill to cost $6 000 000, and the Central Steel Company, at Massillon, will increase its capacity, as will several other mills in the territory. All these mills will be electrically equipped throughout.

FINANCIAL SECTION

DETROIT EDISON COMPANY

The annual report of Detroit Edison Company for 1915 shows how greatly the tremendous automobile business of Detroit has aided this electric generating and distributing subsidiary of North American Company.

Gross earnings of Detroit Edison for 1915 were \$7 759 932, a gain of 19.4 percent over 1914, while net earnings were \$2 948 713, an increase of 28.1 percent. After providing for all charges there was a surplus of \$1,848 658, a gain of 30.3 percent over that for 1914. Detroit Edison Company, by reason of these large gains in earnings, was able in 1915 to increase its quarterly dividend rate from 1.75 percent to two percent. In order to keep up with the demand for its product the company in 1915 spent \$3 581 912 on new construction, and for 1916 its construction budget calls for expenditures of \$5 013 893, of which almost \$3 000 000 will be for additions to its generating stations.

Indicating how rapidly the demand on its generating and distributing facilities are growing, it may be said that in 1915 its electric output was 393 120 850 kilowatt-hours, as compared with 313 718 600 kilowatt-hours in 1914, an increase of 25.3 percent. Its maximum demand load in 1915 was 101 800 kilowatts, as compared to 83 300 kilowatts in 1914, a gain of 22.2 percent. Its load factor in 1915 was 44.1 percent, as compared with 43 percent in 1914.

One of the features, which is shown in the annual report, is the decrease in the average annual bill per consumer. In 1912 the average annual bill was \$20.10; in 1913, \$19.90; in 1914, \$19.50, and in 1915, \$18.90.

PACIFIC GAS & ELECTRIC

To show the magnitude to which its operations have grown, Pacific Gas & Electric Company in its forthcoming annual report will give some statistics indicating the extent of its activities. The capital invested in the company would build six Panama-Pacific Expositions, its employees would make a good-sized town and its stockholders a fair-sized city, its gas mains would extend from San Francisco to Chicago and its electric transmission and distributing lines would encircle the earth. The water stored for its hydro-electric plants would supply San Francisco for 800 days, and it uses in its gas plants three percent of all oil produced in California. Some of the figures show that the company has 4800 employees, to whom it paid \$5 300 000 in wages in 1915, or an average daily wage of \$3.07. It has \$125 000 000 invested in its properties and operates over 37 775 square miles of territory in thirty counties, serving a population of 1 681 894, of whom 401 038 are consumers of its products. In 1915 it expended \$12 141 500 in California for wages and materials and paid out \$722 944 in taxes. It has 121 059 horse-power in ten hydro-electric plants and 109 517 horse-power steam generated energy in four plants, or a total of 230 576 horse-power of generating capacity in fourteen plants.

It has 21 800 miles of electric lines in its distributing system and supplies 740 miles of electric railways with power. It has 40 000 000 000 gallons of water in the 62 storage reservoirs connected with its hydro-electric generating stations. It supplies 50 387 horse-power of electric energy for agricultural purposes, 159 847 horse-power for industrial purposes, supplies current to 37 535 street lights and to 3 460 786 incandescent lamps, and has 520 829 horse-power of connected electric load, which would represent the equivalent of the labor of 2 680 000 men.

In 1915 gross earnings of Pacific Gas & Electric were \$18 530 301, of which \$9 924 482 was from its electric light and power department. This was an increase of \$1 617 613 over gross for 1914. After providing for all expenses, taxes, maintenance and depreciation it had remaining \$8 358 587 to pay \$3 982 419 bond interest and, after providing for this bond interest, had a balance almost three times the requirements for its preferred stock dividends. After providing for the dividends on its preferred stock there was a balance for the year equivalent to 0.45 percent on its \$34 000 000 common stock.

GAINS IN EARNINGS OF ELECTRIC COMPANIES

Electric generating and distributing companies of the country are now reporting probably the largest gains in their history, and these increases in revenues of the electric companies tell something of the increase in prosperity of general business. Net earnings of the Denver Gas & Electric Company in 1915 increased 16.5 percent over 1914, while the Empire District Electric Company, furnishing current to mining and smelting districts of Missouri, Kansas and Oklahoma, reported gains of 38 percent in gross and net. The electric department of Toledo Railways & Light Company reported an output of 100 168 375 kilowatt-hours in 1915, as compared with 91 479 892 kw-hrs. in 1914. Alliance (O.) Gas & Power Company increased its gross 22 percent and its net 38 percent in 1915 over 1914, and the Trumbull Public Service Company, another Ohio corporation, reported an increase of 23 percent in gross and of 54 percent in net as compared with 1914. Massillon (O.) Electric & Gas Company made a gain of 50 percent in gross and of 120 percent in net. The southern states, where for a time conditions were much depressed, also report good gains. At Amarillo, Tex., the electric company reported a gain of 100 percent in net, and at Bristol, Tenn., there was a gain of 10 percent in gross and 32 percent in net. The Brush Electric Company, of Galveston, reported an increase of 12 percent in net. Companies in Kansas reported 12 percent increases in gross and 40 percent increases in net.

COMMONWEALTH POWER, RAILWAY & LIGHT

Commonwealth Power, Railway & Light Company, which controls electric properties in Ohio, Indiana, Wisconsin, Kentucky, Illinois and Michigan, indicates in its report for 1915 the wonderful possibilities in the development of electric companies. Gross of the operated properties in 1915 was \$14 590 124, an increase of \$583 640, or 4.17 percent, as compared with 1914. However, for December, 1915, there was a gain of ten percent in gross as compared with December, 1914. After providing for all charges, and dividends on its preferred stock, the company earned for its common stock 7.42 percent, as compared with 7.13 percent in 1914. In addition to paying regular quarterly dividends of 1.5 percent on its preferred stock quarterly dividends of one percent are paid on the common stock. In 1915 subsidiaries of Commonwealth Power, Railway & Light made a gain of 34 904 174 kilowatt-hours in sales of electric energy and increased the number of electric customers by 12 202. It carried 81 404 051 passengers on its street railways and 9 200 000 passengers on its electric interurban railways. The company put in effect a plan by which its employees may become stockholders in the company. The plan provides for the sale of not more than two shares of common stock for each \$300 yearly wages to employees, the price of the stock to be \$60 a share and payments of \$1 a month to be made, with all dividends being applied to the purchase price.

NEW BOOKS

"Overhead Transmission Lines and Distributing Circuits"—F. Kapper. Translated by F. P. Friedlander. 300 pages, 297 illustrations. Published by D. Van Nostrand Company, New York City. Price \$4.00

This is a very high-grade book explaining the fundamental principles of line design and construction with data essential to the proper carrying out of the different operations. While based on foreign practice, the discussions are largely fundamental and to a considerable extent mathematical. Various types of transmission line structures are considered and analyzed; also forms of foundations for poles and towers; a number of special towers for long crossings are illustrated and analyzed. Two chapters are devoted to overhead line insulators and the attachment of wires to insulators. The various arrangements of overhead wires are explained, including methods of crossing over other circuits, railways, etc. Cost figures are given as to the most economical length of span with comparisons of various forms of supporting structures. Some space is devoted also to local overhead distributing systems.

"Machine Design"—Albert W. Smith and G. H. Marx. 500 pages, 279 illustrations. Published by John Wiley & Sons. Price \$2.75.

This is the fourth edition of this standard work by the director of Sibley College, Cornell University, the present edition being revised by the professor of machine design at Leland Stanford University. In addition to discussions on mechanisms of various types, riveted joints, axles, shafts, bearings, couplings, springs, etc., a valuable chapter is included on roller and ball bearings.

PERSONALS

Mr. B. J. Arnold, consulting engineer, has been selected as one of the board of three engineers to present a report to the city of Chicago providing for a unified and comprehensive system of transportation, including the present surface and elevated lines and the proposed subway. The other members of the committee are Mr. Robert Ridgway and Mr. W. B. Parsons, of New York.

Mr. Brent Wiley has recently been appointed manager of the mill section of the industrial department of the Westinghouse Electric & Mfg. Company, with headquarters at the East Pittsburgh works.

Mr. Charles W. Davis, who has been with the Standard Underground Cable Company since 1900 as manager of the central sales department, general superintendent of construction and manager of the accessories department, has been appointed vice-president and general sales manager of the company.

Mr. H. O. Swoboda, consulting electrical and mechanical engineer, Pittsburgh, has been retained as consulting engineer by the city of Massillon, Ohio, for the purpose of preparing a set of plans and specifications for a new street lighting system. The present contract expires next April, and the city desires to secure a modern system of lighting combined with the highest efficiency.

Mr. R. L. Wilson, superintendent of the railway division of the East Pittsburgh works of the Westinghouse Electric & Mfg. Company, has been appointed assistant general superintendent of the East Pittsburgh works.

Mr. H. W. Gottfried, who has been for the past three years chief of the electrical department of the Compania Ingeniera, Importadora y Contratista of the City of Mexico, has resigned to open an office at Mexico City as commercial engineer and contractor.

Mr. Frederick W. Ballard, formerly commissioner of light, heat and power for Cleveland, Ohio, has resigned to go to Philadelphia, where he has been retained as expert electrical engineer in making a new appraisal of the Philadelphia Electric Company.

Mr. Arthur F. Murray, equipment engineer of the Blake & Knowles Steam Pump Works at East Cambridge, Mass., has resigned to enter the employ of the New England Westinghouse Company, Springfield, Mass.

Mr. E. T. Causer, factory superintendent of the Mitchell-Lewis Motor Company, Racine, Wis., has resigned to accept the position of works manager of the R. D. Nuttall Company, of Pittsburgh, Pa.

Mr. R. C. Allen, who had been connected with the Boston district office of the Westinghouse Electric & Mfg. Company in the industrial department for several years, has resigned to become sales manager of the Standard Engineering Company, Waterbury, Conn. Mr. A. F. Paige, of the Boston office, has been appointed to succeed Mr. Allen.

Mr. E. Chesrown, engineer for the Pittsburgh district office of the Westinghouse Electric & Mfg. Company, has resigned to accept the appointment of special salesman by the American Gas & Electric Co., 30 Church street, New York City. Mr. Chesrown has been connected with the Westinghouse Company for the past twenty-two years.

Mr. C. I. Weaver, new business manager of Hodenpyle, Hardy & Co., Jackson, Mich., has recently resigned to accept the position of general manager of the Eastern Michigan Power Company at Jackson, Mich., having control of all generating and distributing in the Michigan properties.

Mr. C. W. Johnson, formerly manager of the supply department of the Westinghouse Electric & Mfg. Company, Detroit office, has recently accepted the position of new business manager of the Hodenpyle, Hardy & Co. Michigan properties, with headquarters at Jackson.

Mr. C. E. Allen, formerly of the East Pittsburgh sales department of the Westinghouse Electric & Mfg. Company, has recently been appointed manager of the supply department of the Chicago district office.

Mr. H. C. Kendall, formerly of the railway engineering department of the Westinghouse Electric & Mfg. Company, at East Pittsburgh, and later instructor in the electric railway engineering department at the University of Illinois, has resigned as traffic engineer with the Portland Railway Light & Power Company to become efficiency and traffic engineer with the Denver Tramway.

Mr. Carl H Mohr, of the Baltimore district office of the Westinghouse Electric & Mfg. Company, has been transferred to the Atlanta district office of the company.

Mr. S. B. Cooper, who has been engaged in special work in connection with the Westinghouse exhibits at the Panama-Pacific Exposition, is now in the general engineering department of the Company at East Pittsburgh.

Mr. George A. Wieber, formerly with the Westinghouse Machine Company at East Pittsburgh, has accepted the position of chemist with the Bartlett-Haywood Company, of New York.

Mr. G. M. Simmons, engineer with the New York Service Department of the Westinghouse Electric & Mfg. Company, has resigned to accept the position of superintendent of equipment of the Orange County Traction Company, with headquarters at Newburgh, N. Y.

Mr. L. E. Knapp, of the class of 1914 of University of Missouri and a graduate of the sales school of the Westinghouse Electric & Mfg. Company, is now engaged in industrial sales work in the company's Cleveland district office.

Mr. H. T. Hurlock, of the class of 1913 Delaware State College, and a recent graduate of the sales school of the Westinghouse Electric & Mfg. Company, has accepted a position at their Boston office as correspondent in the railway and lighting department.

Mr. Otis A. Mygatt, president of the Holophane Glass Company, Inc., has recently moved into new offices at 340 Madison avenue, New York City.

Mr. Nicholas Stahl has recently been appointed manager, central station section, railway and lighting department, of the Westinghouse Electric & Mfg. Company, with headquarters at the East Pittsburgh works.

Mr. W. L. Conwell, formerly of the New York office of the Westinghouse Electric & Mfg. Company, has been appointed assistant to the president of the Safety Car Heating & Lighting Company.

Mr. H. W. Fisher, chief electrical engineer of the Standard Underground Cable Company, has been appointed in addition to the position of manager of the Lead Cable Works and Rubber Wire and Cable Factories, with headquarters at Perth Amboy, N. J. He has also been made an officer of the Company by virtue of his appointment as assistant secretary.

Mr. W. R. Pinckard, who has been with the Chicago office of the Westinghouse Electric & Mfg. Company for the past nineteen years, has been appointed special representative of the supply department of the Company at Chicago. Mr. Pinckard is well known among electrical men, and during the past year was president of the Chicago Electrical Club.

Mr. C. M. Sullivan, formerly a salesman in the industrial and power division in the Chicago office of the Westinghouse Electric & Mfg. Company, has been transferred to Milwaukee, Wis., as city salesman. Mr. Sullivan is particularly well known among the public service men of Northern Illinois.

Mr. A. Merritt Taylor, director of the department of city transit of Philadelphia, has resigned. Mr. Taylor is president of the Philadelphia & West Chester Traction Company.

Mr. Quinton Adams, of the New York district office of the Westinghouse Electric & Mfg. Company, has been transferred to the supply division of the San Francisco district office.

Mr. O. P. McCord, of the supply division of the San Francisco office of the Westinghouse Electric & Mfg. Company, has resigned to accept a position on the sales force of the Electric Railway and Manufacturers' Company, of San Francisco.

Mr. Elbert Kramer, a graduate of the Westinghouse engineering apprentice course, who had been connected with the Westinghouse exhibit at the Panama-Pacific International Exposition, has taken up work with the San Francisco district office of the company in charge of the sales of heating and cooking apparatus.

Mr. D. W. Blakeslee, formerly with the sales department of the Westinghouse Electric & Mfg. Company, and later assistant professor of electrical engineering of the University of Arkansas, is now engaged in power-plant design for H. Koppers Company, of Pittsburgh, Pa.

WESTINGHOUSE VETERANS PRESENT MEMORIAL TABLET OF THEIR FOUNDER

The Veteran Employes' Association of the Westinghouse Electric & Mfg. Company, at its third annual banquet, held Saturday evening, January 28, in the Fort Pitt Hotel, Pittsburgh, presented to the company a handsome bronze memorial tablet of the late George Westinghouse, founder of the numerous industries bearing his name. This organization is composed of those who have been in the employ of the company for twenty years or more, and is one of the most active of the numerous Westinghouse organizations. About 450 veterans were present, and officers and men from the shop mingled freely with each other and discussed the times when the electrical industry was in its infancy.

President DeKaiser, of the Association, made the opening address, welcoming the veterans and introducing the toastmaster, Mr. John E. Bonham, who is in charge of the clerical division of

the engineering department. The memorial tablet is of solid cast bronze and weighs about 300 pounds. It shows a bas-relief likness of Mr. Westinghouse taken from one of his best photographic poses. It bears the inscription "GEORGE WESTINGHOUSE, Master Workman, Inventor, Founder, Organizer, 1846-1914." It will be placed in the reception room of the East Pittsburgh works of the Electric Company.

The model for this tablet was sculptured by the well-known Chicago sculptor, Lorado Tait, one of America's most famous sculptors. It was cast in bronze and placed in position by Jas. H. Matthews & Co., of Pittsburgh, Pa.

Addresses were made by a number of veterans, former associates of Mr. Westinghouse, including E. M. Herr, president; L. A. Osborne, vice president; N. W. Storer, general engineer; B. Kupferberg, of the storeroom office; Charles F. Scott, consulting engineer, and Guy E. Tripp, chairman of the board of directors. Each speaker referred to some different phase of the great inventor's life which had particularly impressed him.

The tablet was presented on behalf of the veterans by Chas. F. Scott, who, in addition to his duties as consulting engineer, is also professor of electrical engineering, Sheffield Scientific School, Yale University, and was accepted on behalf of the company by Guy E. Tripp.

The memorial was unveiled by Miss Rose Kennedy, one of the four women members of the Veteran Association. It was placed at one end of the hall, and by means of especially erected lights equipped with reflectors it was made visible to all the veterans present.

Chairman of the Board Guy E. Tripp, in accepting the tablet on behalf of the company, said in part:

"History is little more than a biography of great men, and admiration and emulation of them is the real foundation of advancing civilization.

"History has been enriched by the life of George Westinghouse and if we, his associates, have not received some benefit in our own lives, if we have not been encouraged by his example of courageousness, if we have not been incited to new efforts by his perserverance, then we should regret having neglected our opportunities.

"It was an opportunity to have observed his unfettered methods of work—unfettered because he could labor at details without being swallowed up by them, and he could deal comprehensively with the whole without vagueness. He instinctively knew the essential point and swept all other matters aside as of minor importance."

PERSONALS

Mr. O. T. Hertzel, who has been since 1912 employed as railway supply specialist of the detail and supply department of the Westinghouse Electric & Mfg. Company, has resigned to become treasurer of the Electric Specialties Company, of North East, Pa. The new company is organized for the manufacture of electric machinery parts such as commutators, trolley wheels, overhead line material, etc.

Mr. P. H. W. Smith, formerly vice-president and sales manager of the Standard Underground Cable Company, has been made vice-president and assistant general manager under President and General Manager J. W. Marsh. His headquarters will be in Pittsburgh as formerly.

Mr. F. Reibel, Jr., has severed his connection with the Westinghouse Electric & Mfg. Company and has taken a position with the George Cutter Company at South Bend, Ind. He was formerly a salesman in the detail and supply division, and located at Omaha, Neb.

Mr. Harvey E. Brundage, who has been with the Adams & Westlake Company of Chicago for the past six years, has accepted a position in the industrial division of the Chicago office of the Westinghouse Electric & Mfg. Company.

Mr. Arthur A. Anderson, who has been connected with the Pittsburgh sales office of the Standard Undreground Cable Company for a number of years, has been made manager of the central sales department, with headquarters in the Westinghouse Building, Pittsburgh, Pa.

Mr. E. B. McFarland, of Detroit, has recently accepted the position of industrial and power representative of the Westinghouse Electric & Mfg. Company's Detroit office.

NEW BOOKS

"The Applied Theory of Accounts"—P. J. Esquerre. 519 pages. Published by the Ronald Press. For sale by THE ELECTRIC JOURNAL. Price, cloth $3.00, half-leather $3.50.

This is a comprehensive book covering business organizations such as co-partnerships, corporations, the general theory and technique of accounts, including accounting systems, financial books, classification accounts; the theory of the asset accounts, including cash accounts, accounts of customers, notes and bills receivable, accounts with goods, consignment, lands and buildings, building equipment, machinery and tools, patents, investments, reserved funds; the theory of the liability account, including capital account, bonded debt, secured debt, accounts payable, approved liabilities, reserves and surplus; financial statements, including trial balances, statements of income and profit and loss, consolidated balance sheets, the statement of affairs, realization and liquidation. From the preceding outline it will be seen that the subject is covered exhaustedly. Sample forms are used freely to indicate the methods of procedure, with references to other publications having a bearing on the different topics discussed. Such a work should be of great value to those interested in accounting, and especially to smaller organizations who may not have available expert accountants to keep them posted as to the correct methods of procedure.

"Theoretical Elements of Electrical Engineering"—Charles P. Steinmetz. 368 pages, 194 illustrations. Published by McGraw-Hill Book Company, New York City. Price $3.00.

This is the fourth edition of this standard work originally published in 1909, based on a series of university lectures. It can be considered as an introduction to the author's work on "Theory and Calculation of Alternating-Current Phenomena." When the third edition was published very little change was made in the original material. In the present edition there have been radical revisions and re-writing to make room for adequate representation of the theoretical elements of present-day electrical engineering. The scope of the work is substantially the same, and includes numerous examples for class room work. While a certain amount of mathematics is used, especially in explaining fundamentals, the work can hardly be called of a mathematical nature, although, of course, based on mathematical fundamentals. It is understood that the author's "Alternating-Current Phenomena" is also being re-written and revised and that the two will be companion books, with the notations standardized according to the American Institute of Electrical Engineers rules and those of the International Electrical Congress.

"The Corrosion of Iron"—L. C. Wilson. 178 pages. Published by the *Engineering Magazine*. Price $2.00.

This little book is an attempt to put in simple form some of the more interesting and important facts connected with the corrosion of iron, along with protective measures for resisting such action, including descriptions of various protective paints, with a chapter on the corrosion of wrought iron and the steel pipe.

NEW NORMA BEARING CATALOGUE

The Norma Company of America, 1790 Broadway, New York City, have just published a new catalogue on ball and roller bearings. Without departing too far from the accepted forms of good sales literature, they have presented the subject in an interesting manner which will be helpful to engineers and of permanent textbook value. The first 18 pages explain the principles of anti-friction bearings and the design of Norma bearings. Pages 19 to 38 give some principles of anti-friction efficiency written from a strictly engineering standpoint. Some sixty pages are devoted to tabular data giving detailed information regarding various types and sizes of Norma bearings. Pages 100 to 115 contain application drawings suggesting various uses and arrangements of ball bearings. The final pages are devoted to notes and suggestions on the selection of anti-friction bearings. The catalogue is a handsome book mechanically and should be available to everyone interested in this subject. Copies will be sent on request.

GOLD MEDAL FOR HARRISON SAFETY BOILER WORKS

The combined open feed water heater and hot water meter known as the Cochrane metering heater, exhibited at the Panama-Pacific Exposition by the Harrison Safety Boiler Works, Seventeenth street and Allegheny avenue, Philadelphia, has received the gold medal award. This apparatus is designed to heat boiler feed water by means of exhaust steam from engines, pumps, etc., and simultaneously to meter the water and record the rate of flow, and to integrate the total flow in any elapsed period. This enables the engineer or plant owner to determine how many pounds of steam are being evaporated per pound of fuel burned under the boilers, and hence to compare the different fuels, different methods of firing, etc. It also shows the effect upon boiler efficiency of cleaning soot and scale off heating surfaces, stopping up air leaks in furnace and settings, and other improvements in operation, and furnishes the means whereby the methods of obtaining high efficiency may be discovered, standardized and maintained.

A PHILADELPHIA CONCERN LEADS IN PREPAREDNESS

Officers and Men of the Submarine Flotilla of the U. S. Navy Instructed in Storage Practice at the Works of the Electric Storage Battery Company.

Last fall the Electric Storage Battery Company initiated a scheme of instruction for the officers and men operating the submarines of the United States navy. As a result, during the months of November and December each of these men spent one week in hearing lectures on storage battery design and operation delivered by the engineers of the battery company and were also given instruction in shop methods. Over 100 officers and men took this course. About five weeks was devoted by the battery company to this work, the officers and men expressing great appreciation of the help thus received. This course of instruction was originally laid out by the Electric Storage Battery Company and approved by Admiral Grant, chief of the submarine flotilla, and his aide, Captain Yates Sterling, Jr. It was then sanctioned by the Honorable Josephus Daniels, Secretary of the Navy, from whom the Electric Storage Battery Company has received a letter of recommendation for its patriotism.

MORSE CHAIN COMPANY REPRESENTATIVE

The interests of the Morse Chain Company, of Ithaca, N. Y., for the territory including the states of North and South Carolina, will hereafter be taken care of by Mr. G. W. Pritchett, with headquarters at 805 Ashboro street, Greensboro, N. C. Mr. Pritchett is an experienced salesman of machinery and an engineer of repute. With these qualifications, and with his wide circle of personal acquaintances among mill owners and in the engineering profession of the South, Mr. Pritchett will add a strong link in the ever-widening organization of the Morse Chain Company, manufacturers exclusively of silent chains for power transmission.

NEW BOOKS

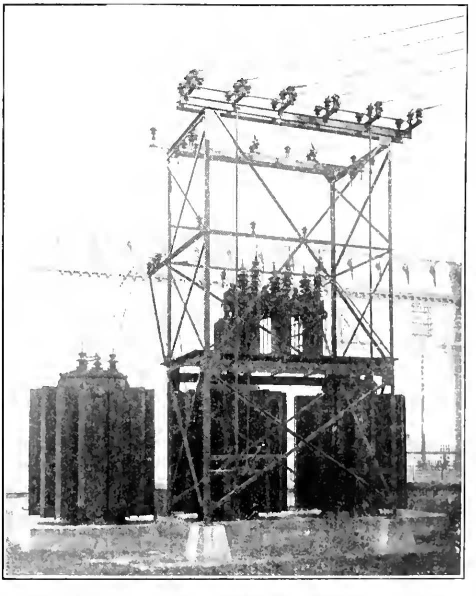
"The Principles of Dynamo Electric Machinery"—Benjamin F. Bailey. 314 pages, 222 illustrations. Published by McGraw-Hill Book Company, New York City. Price $3.00.

This book by the professor of electrical engineering at the University of Michigan is a text designed to present a clear physical conception of the phenomena which take place in electrical machinery. It is essentially non-mathematical in character, aiming rather to give physical ideas of the actions instead. This method of analysis is not so easy, either for the student or for the instructor, but when finally understood it will be of much service to the student in extending his reasoning to new problems. The text is intended for students who do not expect to become professional electrical engineers, although it may be used as a text for those who expect to continue a more advanced course going into the mathematical relations. Vector diagrams are included in such chapters as those on transformers, synchronous generators and induction motors.

"Inventions and Patents"—Philip E. Edelman. 288 pages, illustrated. Published by D. Van Nostrand Company, New York City. Price $1.50.

This volume is intended for those interested in patents, either as inventors, investors or manufacturers. There is a general misconception of patent procedure; in fact, the patent system is completely understood by very few persons. This has resulted in enormous sums being spent on unpatentable ideas and worthless patents. This book shows the steps necessary to secure patents and the mistakes to be avoided. The information given is reasonably complete and should be of considerable value to those interested in patents.

6000 K.V.A. OUTDOOR SUB-STATION



The outdoor substation shown in the accompanying illustration is, no doubt, the most simple high-voltage transformer station of 6000 k.v.a. capacity in operation. It is installed at Cohoes, N. Y., and serves power to one of the largest woolen mills in the world. The station was designed and built by the Railway & Industrial Engineering Company, of Pittsburgh, Pa. The equipment consists of Burke horn gap switches and Burke lightning arresters mounted on the top of the steel structure which carries the oil circuit breakers. The cut shows quite clearly the method of carrying the wiring and connections to the three 2000 k.v.a. Westinghouse transformers.

THE CURB MARKET

FOR SALE

Light Plant for Sale

Instruments, switchboard, exciter, belts, 60 kw. generator, 100 hp. engine, 125 hp. boiler, heater, pump, piping, etc., the complete 60 cycle, 1100 volt electric light plant recently shut down by the Waterford Electric Light Company, Waterford, Pa., on account of purchasing power.

Gas Engine

One 14 horsepower Otto stationary gas engine, in first class condition. Sperlich & Uhlig, 18 Piquette Ave., Detroit, Mich.

RATES

Positions Vacant, Positions Wanted, Agents and Salesmen Wanted—3 cents a word—minimum, $1.50 an insertion—payable in advance.

For Sale, Wanted and all undisplayed miscellaneous ads—3 cents a word—minimum, $1.50 an insertion. Proposals—$2.00 an inch.

Advertisements in display type costs as follows for single insertions:

1–16 page,	$ 4.00	1 in. single col.,	$ 3.00
1– 8 page,	8.00	4 in. single col.,	10.00
1– 4 page,	16.00	8 in. single col.,	20.00

Contract rates on application

FOR SALE

1-220 K.W. A.C. 60-cycle, 1100 volts, 2-phase Generator, direct-connected to a 200 r.p.m. Buckeye engine, with transformers for stepping up to 2200 volts, 3 phase, complete with Barometric condenser, motor-driven condenser pump, switchboard instruments and instrument transformers. Complete details on application to Wisconsin Gas & Electric Co., Racine, Wis.

WANTED

Engine and Generator

High speed direct connected engine and A.C. generator, 2300 volt, 60 cycle, 3 phase, 400 or 500 kw. Also belted set as above. Address Box 508, Hazard, Kentucky.

Technical educated young men for work in our Testing Departments. Good opportunities for experience are to be had. Apply by letter, Employment, Box 911, Pittsburgh, Pa.

Salesman

Eastern headquarters, with established trade wishes a line either exclusively or in conjunction with other goods, for the south, southwest and east

On Tuesday, February 8th, 1916, the Commissioners of the City of Clarksdale, Mississippi, will receive bids on the following second-hand machinery located in the Water and Light Plant at Clarksdale, Miss.

One (1) 12"x14", McEwen Engine, Automatic, Self-Contained.

One (1) 75 K.W., 3 Phase, 60 Cycle, 2300 Volt, self-exciting, belt-driven, General Electric Generator.

One (1) Tennessee Marble Switchboard, for above, complete with all necessary meters, transformers, switches, etc.

The Commissioners reserve the right to reject any or all bids.—M. W. Purnell, Clerk.

FOR SALE

Engine Generator Boiler

One 28" x 56" x 48" cross compound Rice & Sargent engine, direct connected to Westinghouse 1200 K.W., 3 phase, 60 cycle, 2300 v., 90 R.P.M. generator, including Blake Jet Condenser, bronze body. Also twelve Babcock & Wilcox water tube boilers, hp. rating 390; 180 lbs. pressure; including piping, suspensions, Roney Stokers and stoker drive. Boilers may be purchased with or without stokers. All apparatus in excellent condition, ready for immediate delivery. Address Narragansett Electric Lighting Co., Providence, R. I.

Power Plant for Sale

250 hp. tandem compound Skinner engine, 200 r.p.m., direct connected to 200 kva. Crocker-Wheeler generator, 240 volt, 3 phase, 60 cycle, complete with exciter and two panel board. This set has seen very little use. Also two 200 hp. Sterling boilers with 100 ft. sack and in A1 condition. Also Wheeler condenser pump, boiler feed pumps, air compressors, blowers, motors, etc. Will be sold very cheap. Address A. J. Stahl, South Bend, Ind.

7½ horsepower Century motor; 60-cycle, one-phase, 110 or 220 volts. Used three months. Best offer takes it. Address, Electrical Service Co., Crystal Lake, Ill.

WANTED

A Salesman with Technical Education as Mechanical Engineer.

We have an opening for a man who has received a technical education as Mechanical Engineer, and who is experienced as a salesman, to become Head Salesman of our Heavy Capacity Automatic scales for factory and warehouse uses. He should not be younger than thirty nor older than forty years. His personality should be such as to fit him to associate successfully with traveling salesmen and prospective purchasers of Heavy Capacity Scales.

This will be a traveling position. The man should make his residence in Toledo, but will spend only one-third of his time here in our factory office and two-thirds in the field. He must be qualified to talk with authority on the subject of Mechanics with Factory Superintendents, Engineers and Scientific Men, as well as to co-operate effectively with our own corps of Engineers in the development of the **Heavy Capacity Scales**. He must have executive ability and be qualified not only to sell the scales himself but to employ, instruct and direct other salesmen.

This is a difficult position to fill. It requires a man with an unusual training. We are willing to pay a liberal salary.

Address Henry Theobald, President, Toledo Scale Company, Toledo, Ohio. All communications will be guarded as strictly confidential.

THE ELECTRIC JOURNAL

VOL. XIII APRIL, 1916 NO. 4

The Names of Motors

Professor Joseph L. Markley, for many years a teacher of mathematics at the University of Michigan, used to say, "All argument is, to a large extent, a matter of definition." With reference to naming the different types of motors this statement impresses itself in two ways:—First, through the necessity of clearly defining the different types and their characteristics in order to discuss them intelligently; and second, to avoid much fruitless discussion arising from the misunderstanding of common ground. The first may be likened to providing the tools for discussion, and the second to limiting that discussion to material which will yield actual results. Mr. Hellmund's article in this issue on the "Classification and Nomenclature of Electric Motors" gives definite form to many ideas and expressions which have been loosely used in the past with resulting mental confusion. Some of the simpler definitions may seem to be axiomatic, but in work of this nature it is essential that even the elementary conceptions be universally agreed upon, so that they may be used with complete understanding in the more complicated terms.

One of the first impressions made by this list is wonder at the multiplicity of different types. It seems only a few years since the direct-current shunt, series and compound-wound motors and the squirrel-cage and phase-wound induction motors constituted practically a complete catalogue, but at the present time there is offered a bewildering display of different types with almost limitless possibilities. This is particularly true of the alternating-current commutator types. Perhaps there could be no greater indication of the progress of the art than this evidence of increase in numbers of types and this, after all, is only incidental to the real purpose of the article.

The necessity for this cataloguing, which has been so ably carried out, can be illustrated by an old familiar term such as that of "repulsion motor." Probably all designing and operating engineers who are interested would agree perfectly on the characteristics and operation of this motor, and yet to question why it is called a repulsion motor, or to suggest other and better names, is to provoke a flood of profitless argument; for this reason the Institute subcommittee is considering omitting the term entirely and suggests the name "transformer" motor in its stead, which seems a more logical expression. The committee has undertaken a work which requires clear judgment and broad experience, and if the present form is not the final result, it certainly offers opportunity for full and free discussion by everyone concerned and should eventually result in the establishment of standards which will obviate any obscurity due to inadequate definition.

A. M. Dudley

The New Factory Lighting Code

Since sight is necessary for practically all operations connected with a modern industrial establishment, it would seem obvious that satisfactory illumination is essential to a successful factory. That this has been recognized by some of the more progressive manufacturing concerns is evidenced by articles which have appeared from time to time in the technical press —notably those by Mr. C. E. Clewell and others in past issues of the Journal. As a typical example of the commercial value of light may be cited a case in which a loss of time amounting to one or two hours per day on dark days was entirely overcome by the installation of an adequate lighting system, the cost of which did not exceed the wages of the men in the department for more than a few minutes per day. Careful attention to correct lighting may thus produce fully as big results in increased efficiency as do any of the more spectacular schemes of efficiency engineering. This is entirely apart from decreasing the number of industrial accidents which, unless adequate artificial lighting is provided, tends to increase as the hours of daylight decrease.

In this particular, as in the safeguarding of factory machines, it has remained for a few of the more progressive manufacturing concerns to blaze the trail, which is followed at a later date by suitable legislation, serving to urge the less progressive concerns in the same general direction. The question of factory illumination seems to have reached the stage where such legislative requirements are beginning to be enacted. The States of Wisconsin and New York have already taken the initial steps, and the Commissioners of Labor and Industry of Pennsylvania and New Jersey have expressed themselves as being in favor of the adoption of a code of factory lighting by their respective States. It is most fortunate that the various legislatures and commissions, in dealing with so important a subject, can have the benefits of the experience of the most prominent illuminating engineers of the country, as expressed in the new factory lighting code prepared by a committee of the Illuminating Engineering Society and discussed by Mr. C. E. Clewell, chairman of the committee, in this issue.

It is not possible that all of the conditions can be completely covered by such a code. It is rather its object to provide certain minimum conditions which shall serve as a lower limit and also to provide to those concerns which have hitherto neglected this important factor an object lesson of what constitutes satisfactory illumination from the standpoint of the most effective production, as well as of the other incidental benefits to be obtained therefrom.

Chas. R. Riker

The Main Motors and Phase Converter for the Norfolk & Western Locomotives

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Railway Engineering Dept.
Westinghouse Electric & Mfg. Company

The power for the operation of the Norfolk & Western locomotives is delivered from the single-phase trolley to the primary of the locomotive transformer at 25 cycles, 11 000 volts, and is there stepped down to 725 volts. At this voltage the phase converter changes the power from single phase to two phase and then, by means of the well-known Scott connection on the transformer, three-phase energy is supplied to the driving motors, as shown in Fig. 1. There are four driving motors per cab, or eight motors per locomotive, each having an hourly rating of 410 horse-power and a continuous rating of 325 horse-power at the rated voltage and at 14 miles per hour; the continuous rating at 28 miles per hour is 375 horse-power.

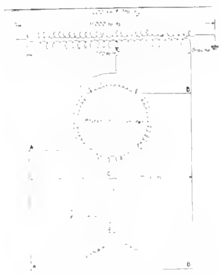


FIG. 1 — SCHEMATIC DIAGRAM OF PHASE CONVERTER AND SCOTT CONNECTION*

The heavy freight service on mountain grades imposes very severe starting requirements. The specifications required that the motors should be able to deliver the maximum drawbar pull for a period of five minutes with the locomotive wheels at rest. Tests taken by a dynamometer car show that the motors are able to deliver 20 percent in excess of this required starting tractive effort.

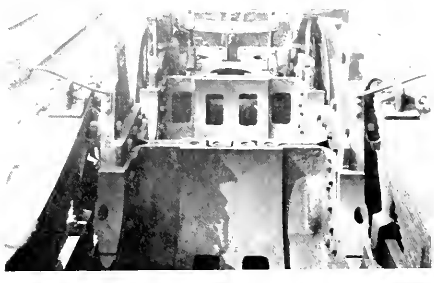


FIG. 2—LOCOMOTIVE FRAME

The motors are of the three-phase wound-secondary induction type, of rugged design to withstand the mechanical shocks peculiar to locomotive service. They are mounted in pairs in each truck, with the pinions of each pair of motors meshing into common gears.

In order to provide convenient facilities for overhauling the locomotives some radical departures from usual railway practice have been made in the design of these motors. Vertical lifts with a crane are by far the more convenient, as the crane operator has more control over the apparatus he is handling in vertical lifts than in sidewise movements; especially is this true in the handling of motors, where there is danger of damaging the insulation. With this in view, the cast steel motor frame was made of semi-cylindrical shape and bolted permanently between the locomotive side frames, as shown in Fig. 2. The stator, rotor and housings together are lowered into this frame and are quickly and conveniently bolted into place.

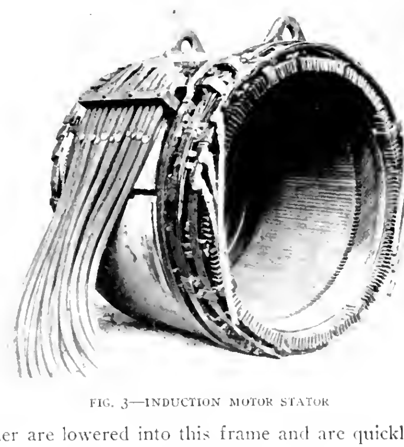


FIG. 3—INDUCTION MOTOR STATOR

The stator is turned to accurate outside diameter to fit the bore of the frame, and is held in place by two steel keys parallel to the axis and bolted to the motor frame. The stator punchings are built up on a mandrel and riveted between cast steel end rings when under hydraulic pressure. The longitudinal holes in the core provide suitable ventilating ducts. The stator winding is of formed diamond shape coils of strap copper insulated with a high-grade heat-proof insulation. Retaining rings on both the inside and outside of the end winding keep the coils rigidly in place. All the wiring around frame details are securely clamped, as shown in Fig. 3.

*For more detailed diagram of connections see Fig. 6, p. 475, of the Journal for Oct., 1915.

The rotor core is assembled on a cast steel spider with the standard dove-tailing of punchings on the spider arms, and the punchings are bolted under pressure between end plates, designed also to serve as supports to the coil extensions. The rotor coils are placed

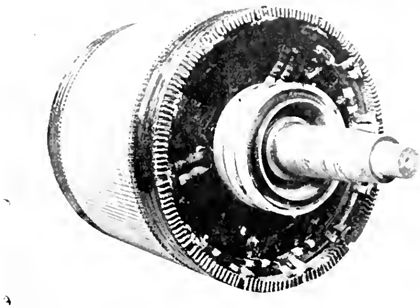
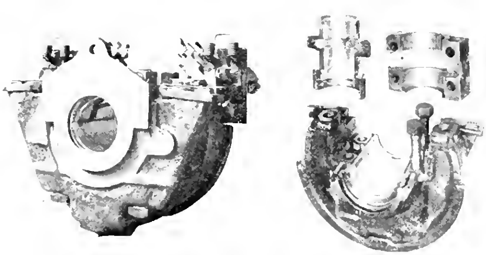


FIG. 4—INDUCTION MOTOR WOUND SECONDARY

in partly closed slots and secured with the usual fibre wedges. The end windings are banded, as shown in Fig. 4, to care for the centrifugal forces incidental to high rotor velocities. The two locomotive speeds of 14 and 28 miles per hour are secured by pole changing of both the rotor and stator. Therefore, six collector rings are necessary, three at each end of the rotor.

Another interesting feature of the motor design is that oil ring lubrication has been adopted. This insures a good flow of oil to the bearings. A cast steel housing contains the bearing and provides suitable oil well capacity, the housing cap being secured by four bolts. Split bronze bearings with babbited linings are used. The upper half bearing has oil grooves to provide for thorough lubrication of the shaft, and there are two oil rings, side by side, to insure lubrication, even though one



FIGS. 5 and 6—MAIN MOTOR BEARINGS

of the rings should become damaged or refuse to turn, due to friction of the ring against the bearing wall. Bearing renewal is accomplished by removing the cap, raising the armature slightly in the air gap and turning the bearing on the shaft, as shown in Fig. 7.

As the locomotives operate in the coal fields the pushing locomotive is frequently enveloped in clouds of coal dust from the tops of the cars, some of which is carried into the air ducts and deposited in the windings. In order to strengthen the windings against the injurious effects of this deposit, both the rotor and stator have been dipped in varnish and then baked, a process which very materially strengthens the insulation against voltage strains due to creepage.

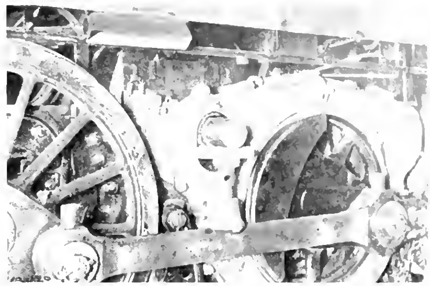


FIG. 7—METHOD OF CHANGING MAIN MOTOR BEARINGS

By means of longitudinal ducts in both the rotor and stator, forced air is taken in at one end and exhausted at the other. With this method of ventilation there are no sharp corners such as occur with radial ventilation. The ventilating air is secured from a blower mounted on the shaft of the phase converter.

To facilitate locomotive overhaul the phase converter is also designed to provide for vertical lifts. The phase converter, starting motor and blower fan are mounted as a unit, which is readily removable from the locomotive. It is also possible to remove all but the frame, leaving the latter bolted in place. Further, the fan, the starting motor stator and rotor are each independently removable.

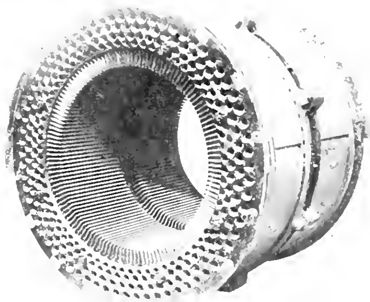


FIG. 8—STATOR [illegible] OF PHASE CONVERTER

The converter frame is of simple construction. Since the machine delivers but little mechanical torque, the frame has only to carry the converter weight and to withstand the vibrations and shocks due to end thrust. The half-cylinder construction, therefore, is ideal for

this service. The starting motor end is liberally ribbed to withstand locomotive end shocks. The frame is faced on the longitudinal center line; therefore it is possible to bore the stator seat, housing seats and starting motor

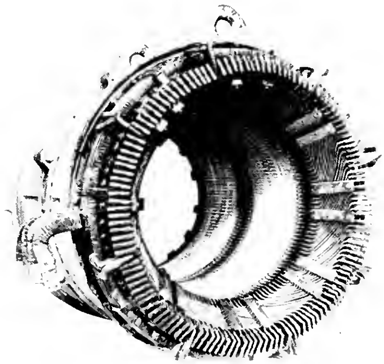


FIG. 9—STATOR WINDINGS OF PHASE CONVERTER

seat with one setting on the boring mill. This provides for accurate alignment of rotors in the air gap.

The stator core, shown in Fig. 8, contains several very interesting features. It was proved by tests that for this particular type of machine central duct ventilation was both economical and effective. The problem then became one of building up a substantial core with suitable ducts and, at the same time, without adding too much to the axial length, since this was a limitation in the design. Two halves were built up independently and riveted under pressure between cast steel end plates. The end plates at the center have lugs which are care-

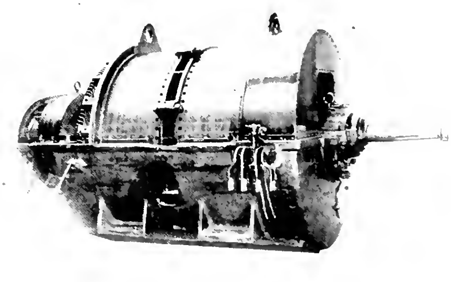


FIG. 10—VIEW OF ASSEMBLED PHASE CONVERTER
The blower is mounted on the shaft extension at the right.

fully machined; a lip on the one engages a recess on the other which centers the two halves during assembly. In order to prevent flaring of the punchings brass finger plates were used, and on account of the depth of iron insulated bolts were properly spaced on a circle near the roots of the teeth. These points are illustrated in Fig. 8, which shows the care that was taken to build up a core free from vibration of iron with the consequent insulation breakdown. In addition, fish paper U-pieces are placed at the end of each slot to prevent the end of the iron from cutting into the insulation. A sheet steel

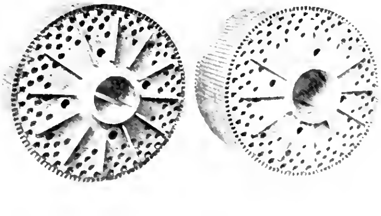


FIG. 11—HALVES OF CONVERTER ROTOR CORE

disc was placed between the two halves so that the exhaust air from one end would not oppose that from the other in the duct. As shown in Fig. 10, the stator winding was very securely clamped to withstand the locomotive vibrations and also the magnetic shocks incidental to starting the converter, the bouncing of the trolley and peak starting loads on the main motors.

The rotor is of the simplest and most rugged design possible. Like the stator, two halves are built up separately and mounted on the shaft with proper slot alignment. The simple squirrel-cage winding of induction motors was used, the rotor bars being electrically brazed to the short-circuit end rings. The converter bearings have oil ring lubrication, and they are of the split type, so that it is possible to remove them without disturbing any other part of the apparatus.

To check the air-gap, maximum and minimum air-gap gauges are used. A cored hole is made in the frame

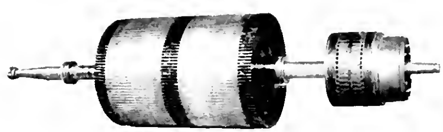


FIG. 12—ROTOR OF PHASE CONVERTER AND STARTING MOTOR

at the proper radius and at the bottom. The gauge is here inserted, a maximum gauge for new bearings, and a minimum gauge to indicate when bearings should be removed.

The starting motor is of the straight series commutator type of liberal design, and is so arranged that its brush-holder bracket, armature or stator can be removed independently.

Skin Effect of a Return Circuit of Two Adjacent Strap Conductors

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WHEN an alternating current flows, a magnetic field is formed around and inside of the conductor. The lines of force of this alternating magnetic field cut the conductor, and thereby produce a voltage drop along it which is not the same at all parts of the section. There is, in general, more effective choking action on the current near the central parts of a conductor than there is near the outermost parts, and so the current tends to crowd toward the outside. This tendency is more pronounced as the frequency becomes higher. The tendency of alternating current to flow in the outside part of a conductor is called the "skin effect."

In this article the calculation of skin effect is described and compared with tested results for the particular case of a return circuit composed of two strap conductors lying in parallel planes close together, as shown in cross section in Fig. 1. This case may be of practical application with low-voltage conductors, and in low-voltage transformers.

A valuable and extensive series of tests of skin effect and reactance has recently been completed.* In this paper it is stated that there are no formulas available for calculating the skin effect of copper strap in practical problems. The formula which was used for giving the nearest approximate calculated value is not useful in practical cases, since the tested values of skin effect are about ten times as great as the values calculated by that formula. The following formula, (*1*), which is believed to be new, gives close agreement with the tests for one position of strap conductors, namely, where the straps lie in parallel planes close together, and by inference it tends to confirm the tests for the other positions. The derivation of the formula is given at the end of this article.

The skin effect impedance ratio in a circuit composed of two wide straps close together in parallel planes is,—

$$\frac{Z'}{R} = \frac{1 + \frac{jm}{2} + \frac{(jm)^2}{4} + \ldots + \frac{(jm)^n}{2n} + \ldots}{1 + \frac{jm}{3} + \frac{(jm)^2}{5} + \ldots + \frac{(jm)^n}{2n+1} + \ldots} \qquad (1)$$

where $m = \dfrac{8\pi^2 f a^2 10^{-9}}{r}$

f = frequency in cycles per second.
a = thickness of strap in centimeters.
r = resistivity of the strap in ohms per centimeter cube.

*"Experimental Researches on Skin Effect in Conductors," by Messrs. A. E. Kennelly, F. A. Laws and P. H. Pierce, *Proc. A.I.E.E.*, August, 1915, p. 1749.

The real component of this ratio is $\frac{R'}{R}$, the "skin effect resistance ratio," that is, the ratio of the resistance for alternating current to the resistance for direct current. The reactance is changed with change of frequency as well as the resistance, the reactance being decreased, while the resistance is increased, by an increase

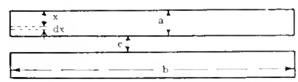

FIG. 1—CROSS SECTION OF RETURN CIRCUIT

of frequency. The amount of this change may be calculated by means of the imaginary component of equation (*1*), which is $\frac{jX'}{R}$, the "skin effect reactance ratio" X' being the reactance due only to flux cutting the strap.

The two series of equation (*1*) are convergent and are the same as those used in the expansion of the hyperbolic sine and cosine. They are of similar form to those used in the expression for "skin effect of an infinitely wide conductor" given in the institute paper referred to, but they involve different constants.

When m is not greater than about *4*, a shorter method than equation (*1*) may be used, and the skin effect resistance ratio may be calculated directly by,—

$$\frac{R'}{R} = 1 + \frac{m^2}{45} - \frac{m^4}{4725} + \qquad (2)$$

and the skin effect reactance ratio by,—

$$\frac{jX'}{R} = \frac{1}{3}\, jm \left(1 - \frac{2m^2}{315} + \frac{2m^4}{31185} \right) \qquad (3)$$

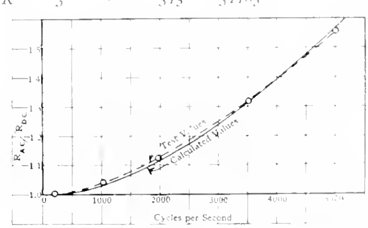

FIG. 2—SKIN EFFECT RATIO,
Size of copper strap, 0.150 by 3.81 cm.

The calculated values of $\frac{R'}{R}$ for the strap conductors described in the paper referred to are plotted in Fig. 2. They are seen to have good agreement with the tested values given in that paper.

An expression for the inductance of the above type of circuit may be derived from equation (3) by adding the effect of the magnetic flux in the air space between the parallel straps. This gives,—

$$L = \frac{2\pi c}{b}10^{-9} + \frac{4\pi a}{3b}10^{-9}\left(1 - \frac{2m^2}{315} + \frac{2m^4}{31185} - \dots\right) \quad (4)$$

henrys per centimeter of strap, where a is the thickness of the straps, b is the width of the straps, and c is the air space between them. Dimensions a, b and c are to be expressed in the same units.

This formula also can be checked by the tests reported in the paper by Messrs. Kennelly, Laws and Pierce. Taking 6638 cm. as the length of strap in the return circuit, which value was furnished to the writer by the authors of the above paper, the calculated values of total inductance plotted in Fig. 3 are obtained, and are seen to agree closely with the measured values.

It is worthy of note that the formula* for the inductance of a return circuit of strap agrees with the tests for low frequencies, except where the spacing is small. When the straps are very close together this formula must not be used, but formula (4) must be used instead.

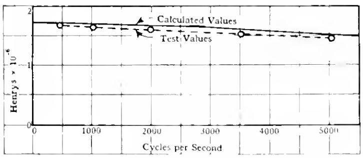

FIG. 3—SELF-INDUCTANCE OF CIRCUIT
Size of copper straps, 0.159 by 3.81 cm.
Air space between them, 0.05 cm.
Total length of strap in return circuit, 6638 cm

Where the spacing is about equal to the width of the strap neither formula gives close results.

DERIVATION OF THE FORMULA FOR SKIN EFFECT AND INDUCTANCE IN A RETURN CIRCUIT COMPOSED OF TWO STRAPS IN PARALLEL PLANES CLOSE TOGETHER

Let the current density at dx, Fig. 1, in amperes per sq. cm. be,—

$$i' = a_0 + a_1x + a_2x^2 + \dots + a_nx^n + \dots \quad (5)$$

The total current between the top surface and dx, per cm. of width of strap, is,—

$$I' = \int_0^x i'dx \quad (6)$$

The flux density at dx is,—

$$\frac{4\pi I'}{10} = \frac{4\pi}{10}\left(a_0x + \frac{a_1x^2}{2} + \frac{a_2x^3}{3} + \dots + \frac{a_nx^{n+1}}{n+1} + \dots\right) \quad (7)$$

The flux between the inner surface of the strap and dx is,—

$$\phi' = \int_x^a \frac{4\pi I'}{10}dx$$

The total drop in volts per cm. of strap is,—

$$V = j2\pi f\phi'10^{-8} + i'r$$

Therefore—,

$$V = j8\pi^2f10^{-9}\left[\frac{a_0a^2}{1\cdot 2} + \frac{a_1a^3}{2\cdot 3} + \dots + \frac{a_na^{n+2}}{(n+1)(n+2)} + \dots\right]$$
$$- j8\pi^2f10^{-9}\left[\frac{a_0x^2}{1\cdot 2} + \frac{a_1x^3}{2\cdot 3} + \dots + \frac{a_nx^{n+2}}{(n+1)(n+2)} + \dots\right]$$
$$+ r\left(a_0 + a_1x + a_2x^2 + \dots + a_nx^n + \dots\right) \quad (8)$$

V is the same for all values of x, since the current takes up such a distribution that the voltage drop is the same at all sections of the strap. Accordingly, the coefficients of x, x^2, etc., may be equated to zero. Thus,—

$$a_1 = 0$$
$$a_2 = \frac{j8\pi^2f10^{-9}}{1 \times 2r}a_0 = \frac{jma_0}{1 \times 2a^2}$$

where

$$m = \frac{8\pi^2fa^210^{-9}}{r}$$
$$a_3 = 0$$
$$a_4 = \frac{jma_2}{3 \times 4\, a^2}$$
$$a_{2n} = \frac{jma_{2n-2}}{(2n-1)(2n)a^2}$$

and

$$V = a_0r + \frac{jmr}{a^2}\left[\frac{a_0a^2}{1\cdot 2} + \frac{a_2a^4}{3\cdot 4} + \dots + \frac{a_{2n}a^{2n+2}}{(2n+1)(2n+2)} + \dots\right]$$

Putting all in terms of a_0,—

$$V = a_0r\left[1 + \frac{jm}{\underline{|2}} + \frac{(jm)^2}{\underline{|4}} + \dots + \frac{(jm)^n}{\underline{|2n}} + \dots\right] \quad (9)$$

The total current per centimeter of width of strap is found by putting $x = a$ in equation (6). Thus,—

$$I = a_0a + \frac{a_2a^3}{3} + \dots + \frac{a_{2n}a^{2n+1}}{2n+1} + \dots$$

By putting all the coefficients in terms of a_0 we obtain,—

$$a_0 = \frac{I}{a\left[1 + \frac{jm}{3} + \frac{(jm)^2}{5} + \dots + \frac{(jm)^n}{2n+1} + \dots\right]}$$

Therefore, from equation (9),—

$$V = \frac{Ir}{a}\,\frac{1 + \frac{jm}{\underline{|2}} + \frac{(jm)^2}{\underline{|4}} + \dots + \frac{(jm)^n}{\underline{|2n}} + \dots}{1 + \frac{jm}{\underline{|3}} + \frac{(jm)^2}{\underline{|5}} + \dots + \frac{(jm)^n}{\underline{|2n+1}} + \dots}$$

Now V is the drop due to alternating current, per centimeter of length of strap, and is equal to IZ' where Z' is the impedance. $\frac{Ir}{a}$ is equal to IR, the drop due to a direct current I, where R is the resistance to direct current per centimeter of the strap. Therefore,—

$$\frac{Z'}{R} = \frac{1 + \frac{jm}{\underline{|2}} + \frac{(jm)^2}{\underline{|4}} + \dots + \frac{(jm)^n}{\underline{|2n}} + \dots}{1 + \frac{jm}{\underline{|3}} + \frac{(jm)^2}{\underline{|5}} + \dots + \frac{(jm)^n}{\underline{|2n+1}} + \dots}$$

which is equation (1).

*Given in the *Bulletin of the Bureau of Standards*, Vol. 8. No. 1. p. 155.

Some Thermal and Mechanical Features of Transformer Windings

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The maximum load that a transformer can carry is limited by the maximum temperature that the insulation can withstand without injury and not by the temperature rise. This maximum temperature is fixed by the A.I.E.E. rules at 105 degrees C. for the materials that ordinarily enter into transformer construction. These rules also assume that the temperature of the hottest spot in the windings may exceed the observable temperature by not more than 10 degrees; this fixes the maximum observable temperature at 95 degrees. An exception is made of oil-insulated, water-cooled transformers, fixing the hottest spot limit at 90 degrees, thus making the maximum observable temperature 80 degrees. There is no apparent good reason for this exception, and most manufacturers will guarantee water-cooled transformers on the same basis as the self-cooled, that is, with a maximum observable temperature of 95 degrees.

FIG. 1—TYPICAL TRANSFORMER COILS

In front is shown a high voltage layer wound coil, partially taped. The coil is wound with small round wire. It is given one layer of tape to bind it together, after which it is impregnated with gum. It is then given another layer of tape, followed by successive dippings in varnish and dryings to fill the tape and give it a good gloss.

At the rear is shown a low voltage cylindrical coil, wound with rectangular wire on a Bakelite micarta insulating cylinder, partially taped. Bakelite micarta end collars are slipped over the cylinder to press against the coil and brace it. After winding and taping, the coil is impregnated in gum.

It is assumed that the maximum temperature of the cooling medium likely to be encountered is 40 degrees for air and 25 degrees for water. On this basis the maximum standard temperature rise allowable by A.I.E.E. rules is $95 - 40 = 55$ degrees for self-cooling, and $80 - 25 = 55$ degrees for water cooled transformers. In any case it is the *actual* temperature of the windings and not the temperature *rise* that counts, and the actual hot spot temperature should not exceed 105 degrees. The lower the temperature of the cooling medium, the greater the load that the transformer can carry safely, and vice versa.

In the past it was the practice to make temperature guarantees for two different loads, generally full load and one and one-quarter load. However, it is now understood that when a transformer is designed to carry its maximum load at a safe temperature, all necessary and essential heating requirements are met, and tests at other loads serve no useful purpose. It is standard practice now to make guarantees on the basis of the maximum single rating; it is also standard practice to provide high-voltage taps for voltages ten percent below normal, and transformers are so designed that they will meet standard temperature guarantees when operating at full k.v.a. output at reduced high voltages corresponding to the taps.

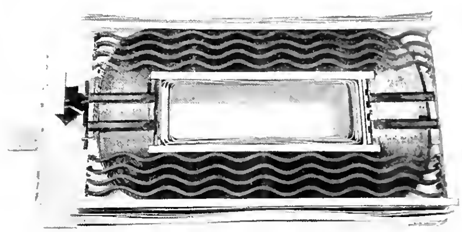

FIG. 2—LARGE SECTION WOUND COIL

Covered with insulating spacers. Showing the heavy insulation between end turns to prevent breakdown from high potential surges.

The standard method of measuring the temperature of transformer windings is the resistance method, although thermometers should be applied as a check wherever this can be done conveniently. Whichever method shows the higher temperature rise should be accepted. For oil-cooled transformers it is generally difficult and often impossible to get a thermometer into close contact with the windings, so that the resistance method is used almost exclusively. For air-blast transformers, thermometers can be inserted in the ventilating ducts in close contact with the coils without much trouble, and in testing this class of transformers thermometers are always used. In air-blast transformers pockets are sometimes found where the air circulates very poorly, and these give rise to hot spots. Thermometers are particularly useful in locating such places.

Thermocouples and resistance coils are very unsatisfactory means of measuring transformer temperatures,

as they will not give reliable indications unless brought into close contact with the conductors. Doing this not only weakens the transformer insulation, but also involves danger in handling the leads coming from the temperature indicating coil. Transformer windings are open and well ventilated and not tightly wrapped and enclosed in slots as in generators, so that hot spots such as may exist in generators are not found in transformers.

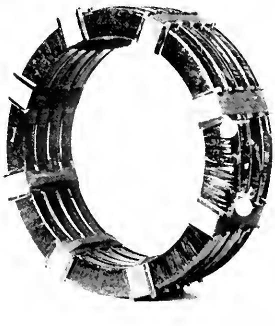

FIG. 3—A FINISHED GROUP OF HIGH-VOLTAGE COILS READY TO BE ASSEMBLED ON THE TRANSFORMER

Showing the spacers which center the high-voltage coils on the cylindrical insulating barrier and provide paths for the free circulation of the cooling oil along the inside surface of the column of coils; also the spacers which separate the individual coils and provide additional cooling surface. Assembling the coils in groups in this manner greatly facilitates the placing of the coils on the transformer.

The temperature of the oil is not of great importance. The temperature of the windings will always be several degrees in excess of that of the oil, and any load that does not produce a dangerous temperature in the windings will not heat the oil beyond safe limits.

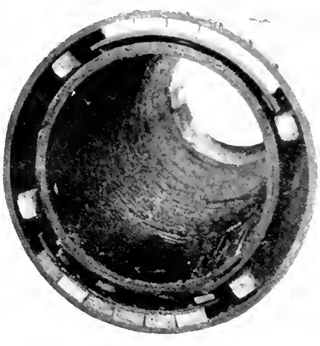

FIG. 4—ASSSEMBLING OF LOW-VOLTAGE COIL, REACTIVE IRON AND CYLINDRICAL INSULATING BARRIER FOR A HIGH-REACTANCE TRANSFORMER

The low-voltage cylindrical coil is wound on the inside micarta cylinder. The reactive iron is cut in strips of proper length and riveted to the ends of the insulating barrier, a section of micarta cylinder separating the reactive iron from the low-voltage coil. This is a most satisfactory way of providing the high reactance necessary for rotary converter operation. The external cylindrical micarta insulating barrier separates the high and low-voltage windings and allows liberal ventilating ducts for cooling the low-voltage winding.

As a rule, the insulation, particularly of air-blast transformers, is separated from the iron by ventilating ducts, so that the iron may operate at a temperature beyond what would be safe for the insulation without in any way injuring the latter. For this reason any arbitrary limitation to the temperature rise of the iron in an air blast transformer is generally a handicap, as it may increase the cost of the transformer without in any way improving its quality. In an oil-cooled transformer, the iron is cooled much better than in an air blast, so that its temperature will very seldom reach that of the windings.

CONDUCTORS

The conductors used for transformer windings are round, square and rectangular copper wires. The small conductors are almost invariably round wire up to and including approximately 0.0007 inch diameter. Square and rectangular wires are very unsatisfactory in these sizes. Square wire is not made in sizes much smaller than 0.0007 inch, and for such small sizes it is difficult to wind because of a tendency to turn on edge and cut through the insulation on the corners of the wire, particularly at the end of a layer when going from one layer to the next. Rectangular wire in such small sizes is also unsatisfactory, because it is so thin that the edges are even more liable to cut through the insulation than square wire, and it is uneconomical of space, because the insulation between layers occupies such a larger proportion of the space as compared with the thin conductor.

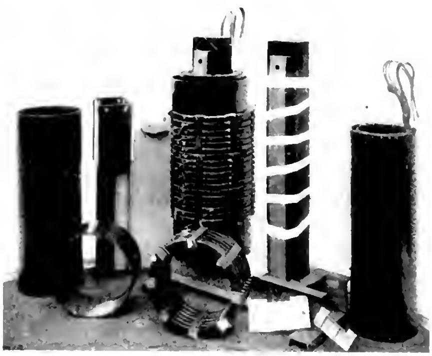

FIG. 5—THE PRINCIPAL PARTS ENTERING INTO THE ASSEMBLY OF A HIGH-VOLTAGE CORE-TYPE TRANSFORMER

Showing the cruciform core held together temporarily by tape ready for the assembly of the winding; the low-voltage coil assembly, including the reactive iron and insulated barrier shown in Fig. 4; and the additional insulating barrier for slipping over the one assembled with the low-voltage coil (one or more such barriers are used, depending upon the voltage of the transformer); the micarta collars for supporting and spacing the columns of the high-voltage coils; the group of high-voltage coils shown in Fig. 3; the boxing for enclosing the tap terminals (taps for voltage variation are brought out from near the middle of the winding); insulating barrier placed between the two columns of high-voltage coils; insulating and ventilating blocks placed under and above the columns of coils; channel iron end frames. A complete winding is shown assembled on one leg of the core.

Transformer coils are divided according to the method of winding into two general classes, namely,

layer wound and section wound coils. Layer wound coils are those that are wound with several layers and several turns per layer, as shown in Figs. 1 and 3. Section wound coils are those that are wound with several layers, but with only one turn per layer. Cylindrical coils wound with square or rectangular wire, as shown in Fig. 1, may be considered as section wound coils when wound with one layer of many turns per layer.

Layer wound coils are nearly always wound with round wire, but occasionally with square wire. They can be wound most satisfactorily in circular form, but they are also often wound in rectangular form. Since the conductors are comparatively small these coils lack stiffness and rigidity and are, therefore, not satisfactory when made in large sizes, particularly if they are of the rectangular form.

Section wound coils are wound with square or rectangular wire; obviously round wire cannot be used, since it would fall apart. Sections may be wound with

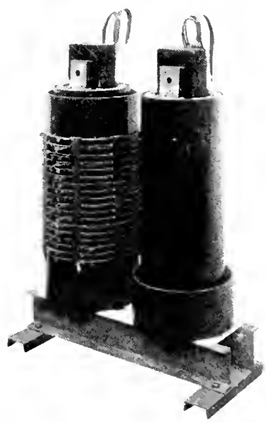

FIG. 6—TRANSFORMER COMPLETELY ASSEMBLED EXCEPT FOR ONE COLUMN OF HIGH-VOLTAGE COILS

one wire or with two or more wires in parallel, depending upon the amount of current to be carried. They can be wound in either circular or rectangular form. A coil may consist of one or two sections assembled together, but if three or more sections are used the inside ones are blanketed in such a way as to get poor ventilation, and therefore become unduly hot. When the wires are of reasonably large cross-section there is no trouble in winding large coils that are mechanically strong and rigid, as shown in Fig. 2. Small section wound coils do not have to be as strong as large ones, and can therefore be wound with smaller wires. For the smaller coils the conductors used are generally of such a width as to give a thickness of coil or section of approximately three-sixteenths to one-fourth inch, and for the larger sizes a thickness of 0.3 to 0.35 inch. If the conductors are much wider than 0.35 inch, the eddy currents are liable to be large and the heating will be increased. The greater the thickness of coil, other things being equal, the less is the area of surface per watt radiated, and therefore the temperature must be higher.

High-frequency disturbances which are set up in electrical transmission and distribution systems, due to

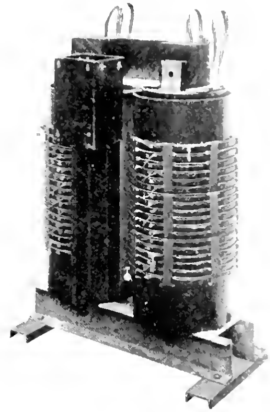

FIG. 7—ALL COILS ASSEMBLED ON TRANSFORMER
Barrier between coils and boxing for tap terminals in place. Yoke partly built in.

various causes, produce extra stresses upon the end windings of transformers. In general, the stresses are greater the higher the voltage of the system. In order

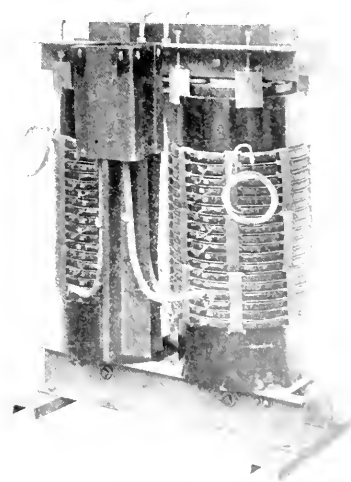

FIG. 8—TRANSFORMER COMPLETELY ASSEMBLED AND READY FOR PLACING IN TANK

to guard against troubles from this source the end coils of the high-voltage windings are wound so as to provide very heavy insulation between the turns. In layer wound coils this is secured by placing heavy insulation

between layers and getting considerable mechanical separation between adjacent turns by winding cord of the same diameter as the wire between them. The number of cords used between two turns varies from one to three, depending upon the amount of mechanical separation required in order to secure the necessary electrical strength. In section wound coils, the extra insulation strength of the end turns is secured by wrapping around the conductors sleeves of paper and cloth that are much heavier than those in the main body of the winding and also placing thick strips of insulation between turns, so as to get considerable mechanical separation, as shown in Fig. 2. These methods of strengthening the end turns have been proved by long and extensive experience to be exceedingly effective in resisting high frequency disturbances. Breakdowns from this cause of transformers insulated in this manner are almost unknown.

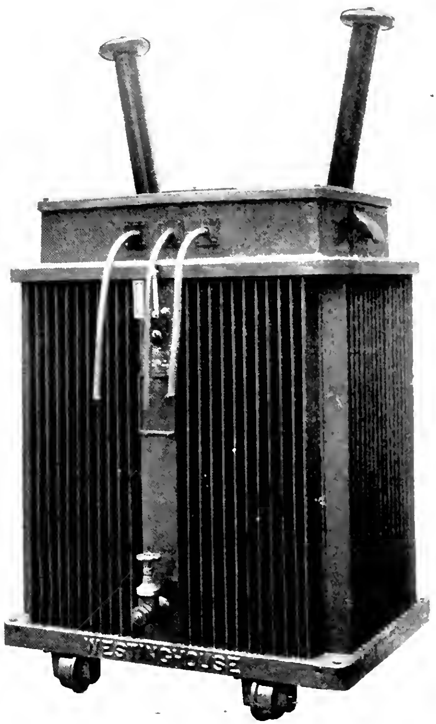

FIG. 9—COMPLETE 75 K.V.A. TRANSFORMER IN SELF-COOLING TANK
Single-phase, 25 cycles, 63 000 to 370 volts, five percent reactance.

In core type transformers the low-voltage coils are generally wound in cylindrical form or in rectangular tubular form, depending upon the shape of the core they have to fit over. They are generally wound with only one layer, although it is not uncommon to have two layers, and more may be used if proper ventilating ducts are provided.

For moderate voltages, say from 2200 to 6600 volts, depending upon the size of the transformer, the high voltage coils are generally wound in the same manner as the low voltage. For higher voltages, the high voltage coils are comparatively thin disc-shaped coils stacked one on top of the other. The coils are generally layer coils, although section wound coils made up of two sections are frequently used. They are made thin so as to secure good cooling and, in addition, ventilating ducts are provided wherever necessary. The insulating barrier between high voltage and low voltage windings, in the type of transformers shown in Figs. 5 to 10, consists of a micarta tube. These tubes have very high dielectric strength, are rigid and strong mechanically, are not affected by oil, and are in every way the best barriers that have yet been devised for providing insulation between the high voltage and low voltage windings of core type transformers. The surfaces are straight and smooth and provide an ideal path for the flow of the cooling oil as it passes through the ducts placed between the barrier and the low voltage coils on one side and the high voltage on the other. The coils are braced at the ends of the columns so as to hold them rigidly in place and prevent distortion or destruction on short-circuit.

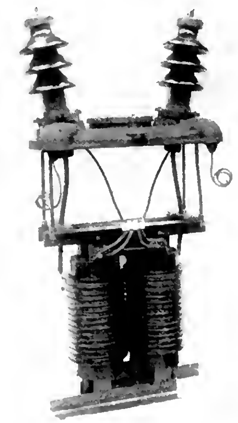

FIG. 10—SMALL HIGH-VOLTAGE OUTDOOR TRANSFORMER

In which the high-voltage coils are wound directly on a Bakelite micarta insulating barrier and then impregnated in gum. The transformer is bolted to the cover, in which there is a hand hole through which access may be had to the low-voltage terminal block. The low-voltage leads are brought out of sealed pockets in the corners of the cover. Only small transformers in boiler iron tanks have the transformer bolted to the cover. Transformers using cast-in tanks cannot be made in this way.

For the lower voltages the core is sometimes rectangular, but for the higher voltages it is generally cruciform in shape. Round coils fit well over a cruciform, and this shape of coil is best for high voltage windings using round wire. In winding a coil on a round centerblock there is an even pressure all the way around, thus making the coil easy to wind; while on the other hand in winding a rectangular coil there is a heavy pressure between layers on the corners and almost no pressure on the straight part, thus requiring greater skill and care on the part of the winder. In winding a section wound coil with square or rectangular wire there is only surface contact between layers, so that there is no danger of the insulation being injured by the pressure on the corners of such a coil.

The sheet steel core is built up of rectangular shaped punchings of the proper sizes, the top yoke being built in after all the coils are in place. It is desirable to have as few holes as possible through the punchings, since wherever they pass through, the cross-section of the core is reduced and the iron loss is increased somewhat, due to the increased flux. The effect is more marked in the cores than in the yokes. It is difficult to fasten the end frames securely without bolt holes through the yokes, so that these holes are provided for practically all core type transformers. For the smaller sizes there are no holes through the cores, a wrapping of tape being sufficient to hold the punchings together. For the larger sizes, however, taping is not sufficient to hold the cores together with the necessary stiffness and therefore bolts, riveted on the ends, are used. Bolts or rivets are also insulated from the punchings by micarta tubes and fullerboard washers. This is necessary in order to prevent the main magnetic field from setting up currents in the loop formed by two bolts and the end laminations, which would considerably increase the losses and might be sufficient to produce a burning temperature.

FIG. 11—30 K.V.A., 33 000 TO 2300 VOLT TRANSFORMER SHOWN IN FIG. 10

Complete in tank ready for service.

Low voltage leads are brought up to heavy terminals mounted on an insulated bar for currents of approximately 700 amperes, or more, and to studs mounted in porcelains for smaller currents. On high voltage windings, taps for voltage variation are brought out near the middle of the winding. By this arrangement the outlet leads are fastened permanently to the end terminals of the windings. Changes in voltage ratio are made simply by changing the position of links across the tap terminals, as shown in Fig. 12. It is very difficult to bring out taps near the ends of high voltage windings without weakening the insulation and increasing the danger of breakdown due to the heavy stresses produced by high frequency disturbances.

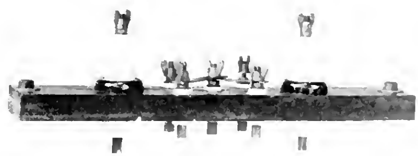

FIG. 12—TYPICAL HIGH-VOLTAGE TERMINAL BOARD

The particular board shown is the type used for voltages of approximately 22 000 to 33 000. Line leads are connected permanently to the terminals coming up through the two large end porcelains. The terminals mounted in the small porcelains near the center are for taps brought out from near the center of the winding, for the purpose of cutting out part of the winding and thus changing the voltage ratio.

Some Limitations in Commutating Machines*

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In addition to certain limitations already discussed† there are a number of other factors which are related closely to commutation; one of these is the permissible current density in the brushes or brush contacts. There are two currents to be considered,—the work current and the short-circuit current which is purely local to the short-circuited coils and the brush. The *true* current density is that due to the actual resultant current in the brush tip or face, which is very seldom uniform over the whole brush tip. The "apparent" current density is that due to the work current alone—assumed to be uniform over the brush tip. The current density has commonly been assumed to be the total work current divided by the total brush section. This method has been very misleading, resulting in many cases in the use of a wrong size of brush to meet some specified current density. In many of the old non-commutating pole machines the local currents were predominant under certain conditions of load, for the brushes had to be set at the best average position, so that at some average load the commutating conditions would be best. At higher and lower loads the short-circuit currents were usually comparatively large. The wider the brush contact, circumferentially, the greater were the short-circuit currents and the higher the actual current density at one edge of the brush, while the apparent density would be reduced. The fallacy of this procedure was shown in many cases in which the brush contact was very greatly reduced by grinding off one edge of the brush. Very often a reduction in circumferential width of contact to one-half resulted in less burning of the brush face. The apparent density was doubled, but the actual maximum density

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*Based on a paper read before the American Institute of Electrical Engineers, September, 1915.

†See the Journal for February, 1916, p. 78, and March, 1916, p. 145.

was reduced. Many of these instances showed very conclusively that much higher true current densities were practicable, provided the true and apparent densities could be brought more nearly together. This is what has been accomplished to a considerable extent in the modern well-designed commutating-pole machine. In such machines the current distribution at the brush face is nearly uniform under all conditions of load. In consequence, it has been possible to increase the apparent current densities in the brushes very considerably, while still retaining comparatively wide brush faces. In fact, the width of the brush contact circumferentially is not particularly limited if the commutating field flux can be suitably proportioned. In many old-time machines, an apparent density of 40 amperes per square inch under normal loads was considered as amply high, while at the present time, with well-proportioned commutating poles, 50 percent higher apparent densities are not uncommon.

Unequal division of current between the brushes on the same brush arms is, to some extent, dependent upon the total current per arm. Where there are many brushes in parallel and the total current to be carried is large, it is obvious that one brush may take an excessively large current without materially decreasing the current carried by the other brushes. As a rule, the larger the current per arm, the more difficult is the problem of properly distributing the current among all the brushes.

In the same way, the division of current among brush arms of the same polarity is not always satisfactory; 50 percent variation of current between different arms is not unusual, and the writer has seen a number of instances where the variation has been 100 percent or more. Obviously, with such variation, it is not practicable to work the brushes up to the maximum density possible, for some margin must be allowed for such unbalancing.

Experience has shown that when current passes through a moving contact, as from a brush to the commutator copper, or *vice versa*, a certain action takes place which resembles electrolytic action to some extent. It might also be said to resemble some of the actions which takes place in an arc. Minute particles appear to be eaten or burned away from one contact surface, and these are sometimes deposited mechanically upon the opposing surface. The particles appear to be carried in the direction of current flow, so that if the current is from the carbon brush to the copper, the commutator face will tend to darken somewhat, evidently from depositation of carbon. If the current is from the copper to the carbon, the brush face will sometimes tend to take a coating of copper, while the commutator face will take a clean, and sometimes raw, copper appearance. As the current is in both directions on the ordinary commutator, this action is more or less averaged, and therefore is not usually noticed. With one polarity or direction of current, the commutator face eats away, while with the other direction, the brush face is eaten away and may lose its gloss. This action of the current gives rise to a number of limiting conditions in direct-current practice. This "eating away" action occurs with all kinds of brushes, and with various materials in the commutator. It appears to be dependent, to a considerable extent, upon the losses at the contact surface. In other words, it is dependent upon both the current and the contact drop. With reduction in contact drop, this burning action apparently is decreased, but in commutating machinery this reduction cannot be carried very far, in most cases, on account of increase in short-circuit current, which nullifies the gain in contact drop. In fact, in each individual machine there is some critical resistance which gives least loss and least burning at the contact surfaces.

Practice has shown that this burning action is very slow at moderate current densities in carbon and graphite brushes—so slow as usually to be unnoted. However, if the actual current density in the brush face is carried too high, the burning of the brushes may become very pronounced. With the actual work current per brush usual in present practice, the burning of the brush face may usually be credited to local currents in the brushes. It is not uncommon, in examining the brushes of a generator or motor, to find a dull black area under one edge of the brush, which obviously has been burned, while the remainder of the brush face is brightly polished. In severe cases, practically as good results will be obtained if the burned area is entirely cut away by beveling the edge of the brush.

This eating away of either the brush face or the commutator, and the deposit upon the opposing face, leads to certain very harmful conditions. As stated before, if the true current density is kept sufficiently low in the contact face, the burning is negligible in most cases. However, where the current passes from the commutator to the brush, it is the commutator copper which is eaten away, while the mica between commutator bars does not eat away, but must be worn away at the same rate that the copper is burnt, if good contact is to be maintained. Let the burning of the copper gain ever so little on the wear of the mica, then trouble begins. The brush begins to "ride" on the mica edges and does not make true contact with the copper. This increases the burning action very rapidly, so that eventually the mica stands well above the copper face. This is the trouble usually known as "high mica." It is frequently credited to unequal rates of wear of copper and mica. This idea of unequal wear has been partly fostered by the fact that with relatively thick mica the action is greatly increased, or, with very thin commutator bars, with the usual thickness of the mica, the high mica trouble becomes more serious. In both these latter cases, it is the higher percentage of mica, that is, the relatively poorer wearing characteristics of the mica itself, which is at fault. But the commutator copper does not *wear away*. In fact, it is not physically possible for it to *wear* below the mica. It is "eaten away," as described above. In some special cases, where this burning is unusually severe, the mica apparently wears

down about as fast as the copper, so that the commutator remains fairly clean and has no particularly burnt appearance, but grooves or ridges, showing undue wear. But this rapid apparent wear is an indication that excessive burning action is present at times, usually due to excessive local currents. In some cases, this burning action may be present only during heavy or peak loads, which may be so interspersed with periods of light running that the true wear of the mica catches up with the burning of the copper. In such cases the commutator may have a beautiful glossy appearance normally, but may wear in grooves and ridges. On account of this burning action, practice has changed somewhat in regard to staggering of brushes on commutators to prevent ridging between the brushes. Formerly, it was common practice to displace all the positive brushes one direction axially, and the negatives in the other direction, in order to give the brushes overlap. This, however, did not entirely prevent ridging, for the burning of the copper occurred only under one polarity. It is now considered better practice to stagger the arms in pairs.

With commutating-pole machines, the true current densities in the brushes are carried up to as high a point as the non-burning requirements will permit. Therefore, conditions for burning and high mica are still existent, as in non-commutating pole machines. In recent years, an extension of an old practice has been very generally adopted, namely, undercutting the mica between bars. During the last few years extended experience has shown that graphite brushes, or carbon brushes with considerable graphite in them, are extremely good for collecting current, but on the other hand, are very poor when it comes to wearing down the mica, due to their softness or lack of abrasive qualities. Due to the graphite constituent, such brushes are largely self-lubricating, and therefore "ride" more smoothly on the commutator than the ordinary carbon brush. They are, therefore, much quieter, and this is a very important point with high speeds. However, by undercutting the mica, all difficulty from lack of abrasive qualities in the brush is overcome, and thus the good qualities of such brushes can be utilized. The advantage of self-lubricating brushes should be apparent to anyone who has had difficulties from chattering and vibration of brushes, due to lack of lubrication. Chattering means bad contact between the brush and commutator, which in turn means sparking and burning.

When the commutator copper burns away to any extent it may deposit on the brush face following the direction of the current. This coating on the brush face sometimes leads to serious trouble, by lowering the resistance of the contact surface. This not only allows larger short-circuit current and greater heating of the brush, but it makes the resistance of that particular path lower than that of other parallel brush paths. In consequence, the coated brush takes an undue share of the total current, as well as an unduly large local current. The resultant heating may be such that the brush actually becomes red hot. This frequently causes disintegration of the binding or other material in the brush, so that it gradually honeycombs at or near its tip. This action of transferring copper to the brush is sometimes known as "picking up copper." Glowing and honeycombing of brushes is not necessarily dependent upon the metallic coating on the brushes. Anything that will unduly increase the amount of current in any brush contact for a period long enough to result in heating and lower contact resistance, with brushes in parallel, may start this glowing and honeycombing.

As an evidence that poor contact or high contact drop tends to produce burning may be cited the fact that in many cases of apparent rapid wear of the commutators such wear has been practically overcome by simply undercutting the mica and thus allowing more intimate contact between brush and copper. In some instances this also lessened or eliminated the tendency to pick up copper. Thus undercutting has been very beneficial in quite a number of ways.

NUMBER OF SLOTS, CONDUCTORS PER SLOT, ETC.

There are certain limitations in direct-current machines, depending upon the minimum number of slots per pole which can be used. Provided satisfactory commutating conditions can be obtained, it is in the direction of economy to use a relatively small number of slots per pole, with a correspondingly large number of coils per slot. Insulating space is saved, thus allowing an increase in copper or iron sections, and wider slots are favorable to commutation. But if this is carried too far certain disadvantages arise, so that at some point they overbalance the advantageous features. As the slots are widened and the number of teeth diminished, variations in the reluctance of the air-gap under the main poles, with corresponding pulsations in the main field flux, become more and more pronounced. These may effect commutation, as the short-circuited armature coils form secondary circuits in the path of these pulsations. But before this condition becomes objectionable other troubles are liable to become prominent, such as "magnetic noises," etc. If the machine is of the commutating-pole type, there are liable to be variations in the commutating pole air-gap reductance, so that it may be difficult to obtain proper conditions for commutation. A relatively wide commutating zone is required if there are many coils per slot; also, all the conductors per slot usually will not commutate under equal conditions, which may result in blackening or spotting of individual commutator bars symmetrically spaced around the commutator, corresponding to the number of slots. In non-commutating pole machines it may be difficult to find a suitable field or magnetic fringe in which to commutate, and thus the first and last coil in each slot will have quite different fluxes in which to commutate.

In small and medium capacity railway motors, where maximum output in minimum space is of first importance, the number of slots per pole used is probably lower than in any other line of direct-current machines, six to eight per pole being rather common. In the small and medium size stationary motors, where noise must be

avoided, a somewhat larger number of slots is used. On still larger apparatus, ten slots or more per pole are used in most cases and, in general, more than 12 are preferred. In large 600 volt machines the number is fixed partly by the minimum number of commutator bars per pole and the number of coils per slot. Assuming three coils per slot, then with a minimum number of commutator bars of about 40 per pole, the minimum number of slots per pole will be 14 and, with two bars per slot, will be correspondingly larger. This, therefore, represents one of the limits in present practice.

NOISE, VIBRATION, ETC.

A fundamental cause of noise in direct-current machines lies in rapid pulsations in magnetic conditions. Numerous solutions of the problem have been proposed, but many of them appear to hold only for the particular machine, or line of machines, for which they were devised. A remedy in one machine not infrequently proves a failure on the next one. There are certain remedies for noise in direct-current machines which apply to all machines but, as a rule, such remedies mean more expensive construction. In general, large air-gaps and gradual tapering of the flux at the pole edges tend toward quiet operation. A large number of slots per pole tends toward quietness. However, the trend of design has been toward very small air-gaps; also, the aim has been to use as few armature slots as possible. Moreover, newer designs with steel or wrought iron frames, as a rule, have the magnetic material in the frames reduced to the lowest limit that magnetic conditions will permit. Also, with the general use of commutating poles, the tendency has been toward "strong" armatures and correspondingly weak fields, so that the total field fluxes and field frames are relatively small compared with the practice of a few years ago. With these small frames, resonant conditions not infrequently are encountered, especially in those machines which are designed to operate over a very wide range of speed. There is liable to be some point in the speed range where the poles or frame, or some other part, is properly tuned to some pulsating torque or "magnetic pull" in the machine. In such case, a very slight disturbance of a periodic nature may act cumulatively to give a very considerable vibration and consequent noise.

The pulsations in magnetic conditions may be due to various causes but, as a rule, the slotted armature construction is at the bottom of all of them. Open type armature slots usually are much worse than partially closed slots. Such open slots produce "tufting" of the magnetic flux between the field and armature, and it is this bunching of flux which usually, in one form or another, produces a magnetic pulsation or pull which sets up vibration. This bunching of lines may be such as to set up pulsating magnetic pulls at no-load as well as full load. In other cases, the ampere-turns in the armature slots tend to exaggerate or accentuate the bunching so that the vibration varies with the load. This bunching of the flux may act in various ways. The total air-gap reluctance between the armature and main poles may pulsate, so that the radial magnetic pull between any main pole and the armature will pulsate in value. If the reluctances under all the poles are varying alike, then these pulsating radial pulls will tend to balance each other at all instants. However, if the reluctances under the different poles do not vary simultaneously, then there are liable to be unbalanced radial magnetic pulls of high frequency, depending upon the number of armatrue teeth, speed of rotation, etc. If this frequency is so nearly in tune with the natural period of vibration of some part of the machine, such as the yoke, poles or pole horns, armature core and shaft, that a resonant condition is approximated, then vibration and noise are almost sure to occur.

Radial unbalanced pulls, as described, are liable to occur when the number of armature teeth is other than a multiple of the number of poles; and the smaller the number of teeth per pole, the larger will be the unbalancing in general. As a remedy, it might be suggested that the number of armature slots always be made a multiple of the number of poles. However, there are several objections to this. One serious objection is that, on small and moderate size direct-current machines, the two-circuit type of armature winding is very generally used and, with this type of winding, the number of armature coils and commutator bars must always be one more or less in number than some multiple of the number of pairs of poles. Mathematically, therefore, with a two-circuit winding, the number of slots can never be a multiple of the number of poles unless an unsymmetrical winding is used, that is, one with a "dummy" coil. A second objection to using a number of slots which is a multiple of the number of poles is that there are pulsating magnetic pulls which may be exaggerated by this very construction. There are two kinds of magnetic pulls—a radial, which has already been considered, and a circumferential, due to the tendency of the armature core to set itself where it will enclose the maximum amount of field flux. Obviously, if the arrangement of slots is such that when one pole has a maximum flux into the teeth, another pole has a minimum, then the circumferential pulsations in torque will be less than if all poles enclosed the maximum or the minimum flux simultaneously. This latter condition will be produced when the number of armature slots is a multiple of the number of poles. Therefore, in avoiding unbalanced radial magnetic pulls by using a number of armature slots which is a multiple of the number of poles, the designer is liable to exaggerate the circumferential variations in torque or pull, so that he is no better off than before. The circumferential pulsating magnetic pull may act in various ways to set up vibration, and if there is any resonant condition in the machine, vibration and noise will result.

Skewing of the armature slots, or of the pole faces, has proven quite effective in some cases of vibration and noise. Tapered air-gaps at the pole edges have also proven effective in many individual cases. However, the causes of the trouble and the remedies to be applied in specific cases are so numerous and so varied that at

present it is useless to attempt to give any limitations in design as fixed by noise and vibration due to magnetic conditions.

"FLICKERING" OF VOLTAGE AND "WINKING" OF LIGHTS

From time to time cases have come up where noticeable "winking" of incandescent lights occur, this being either of a periodic or non-periodic character, the two actions being due to quite different causes. In either case the primary cause of the difficulty may be in the generator itself, or it may be in the prime mover. The characteristics of the incandescent lamp itself tend, in some cases, to exaggerate this winking. To be observable when periodic, the period must be rather long, corresponding to a very low frequency. Periodic flickering of voltage may be considered as equivalent to a constant direct-current voltage with a low-frequency, small-amplitude, alternating e.m.f. superimposed upon it. Tungsten lamps for the same candle-power are more sensitive than carbon lamps, due to their less massive films. In fact, trouble from winking of lights has become much more pronounced since the general introduction of the lower candle-power, higher efficiency incandescent lamps.

In view of the fact that winking has been encountered with machines in which no pronounced pulsations in voltage appear to be possible, a series of tests was made some years ago to determine what periodic variation was noticeable on ordinary low candle-power tungsten and carbon lamps. A lamp circuit was connected across a source of constant direct e.m.f., and in series with this circuit was placed a small resistance which could be varied at different rates and over varying range. The results were rather surprising in the very low pulsations in voltage which showed flickering of the light when reflected from a white surface. With the ordinary frequencies corresponding to small engine-type generators, that is, from five to ten cycles, periodic variations in voltage of 0.5 percent above or below the mean value were sufficient to produce a visible wink with 16 candle-power carbon lamps, while one percent variation above and below was quite pronounced. With corresponding tungsten lamps only about half this variation is sufficient to produce a similar wink.

It is probable that non-periodic fluctuations in voltage do not have as pronounced an effect as is the case with periodic fluctuations, if they do not follow each other at too frequent intervals, unless each individual pulsation is of greater amplitude, or is of longer duration.

Periodic Fluctuations—Variations in prime mover speed can act in two ways; first, by varying the voltage directly in proportion to the speed, and second, by varying the voltage indirectly through the excitation, the action being more or less cumulative in some cases. Such speed variations usually set up pulsations corresponding directly to the revolutions per minute and independent of the number of poles on the machines. In the machine itself, periodic pulsations of frequency lower than normal frequency of the machine itself may be caused by magnetic dissymmetry of some sort, or by unsymmetrical windings. Usually, such dissymmetries give voltage fluctuations at a frequency corresponding to the normal frequency of the machine, and therefore will have no visible effect unless such normal frequency is comparatively low, which is usually the case in engine type direct-current generators. In other cases, these dissymmetries may give pulsations corresponding to the speed, and not the number of poles. For instance, if the armature periphery and the field bore are both eccentric to the shaft, then magnetic conditions are presented which vary directly with the speed.

However, there have been cases where no dissymmetry could be found, and yet which produced enough variations to wink the lights. Usually in such cases, the number of armature slots per pole was comparatively small, and the trouble was overcome by materially increasing the number of slots per pole. A second source of winking has been encountered in some three-wire machines in which the neutral tap is not a true central point. In such case, the neutral travels in a circle around the central point and impresses upon the direct-current voltage a pulsation corresponding to the diameter of the circle. Its frequency, however, is that of the machine itself and is, therefore, more noticeable on low-frequency machines, such as engine-type generators.

Non-Periodic Pulsations or Voltage "Dips"—In all direct-current generators there is a momentary drop or "dip" in voltage with sudden applications of load. The explanation of this dip in voltage is as follows:—Assume, for instance, a 100 volt generator supplying a load of 100 amperes, that is, with one ohm resistance in circuit. The drop across the resistance is, of course, 100 volts. Now, assume that a resistance of one ohm is thrown in parallel across the circuit. The resultant resistance in circuit is then one-half ohm. However, at the *first instant* of closing the circuit through the second resistance, the total current in the circuit is only 100 amperes, and therefore the line voltage at the first instant momentarily must drop to 50 volts. However, the e.m.f. generated in the machine is 100 volts, and the discrepancy of 50 volts between the generated and the line volts results in a very rapid rise in the generator current to 200 amperes. If the current rise could be instantaneous, the voltage dip would be represented diagrammatically by a line only, that is, no time element would be involved. However, *the current cannot rise instantaneously in any machine*, due to its self-induction, and therefore the voltage dip is not of zero duration. The current rises according to an exponential law, which could be calculated for any given machine if all the necessary constants were known. However, such a great number of conditions enter that it is usually impracticable to predetermine the rate of current rise in designing a machine, and it would not change the fundamental conditions if the rate could be predetermined.

A rough check on the above theory could be obtained by means of oscillograph tests. For example, it was assumed that with one ohm resistance in circuit, an equal resistance was thrown in parallel, which dropped

the voltage to one-half. In practice the actual drop which can be measured might not be as low as one-half voltage, as the first increase in current might be so rapid as to prevent the full theoretical dip from being obtained. However, an oscillograph would show a certain amount of voltage drop. If now, after the current has risen to 200 amperes and the conditions become stable, another resistance of one ohm is thrown in parallel with the other two resistances of one ohm each, then in this latter case the resultant resistance is reduced to two-thirds the preceding value, instead of one-half, as was the case in the former instance. Therefore, the dip would be less than in the former case. Again, if one ohm resistance is thrown in parallel with three resistances of one ohm each, the resultant resistance becomes three-fourths of the preceding value,—that is, the voltage dip is still less. Therefore, according to the above analysis, if a given load is thrown on a machine, the dips will be relatively less the higher the load the machine is carrying. Also, if the *same percentage* of load is thrown on each time, then the dips should be practically the same, regardless of the load the machine is already carrying. Also, according to the above theory, a fully compensated field machine (that is, one with a distributed winding in the pole faces proportioned to neutralize correctly the armature magnetomotive force) should also show voltage dips with load thrown on.

An extended series of tests has shown that, in most cases, 10 to 15 percent of the rated capacity of the generator can be thrown on in a single step without materially affecting the lighting on the same circuit, and provided the prime mover holds sufficiently constant speed. However, judging from the quickness of the voltage recovery, the prime mover, if equipped with any reasonable flywheel capacity, cannot drop off materially during the period of the voltage dip as shown in the curves. The dip in voltage due to the flywheel is thus apparently something distinct from the voltage dip due to the load. However, if the load is thrown on in successive increments at a very rapid rate, the result will be a dip in voltage due to the prime mover regulation, although the voltage dips due to the load itself may not be noticeable.

The above gives a rough outline of this interesting but little understood subject of voltage variations. Going a step farther, a similar explanation could be given for voltage rises when the load is suddenly interrupted, in whole or in part. This is usually known as the inductive kick of the armature when the circuit is opened. This may give rise to momentarily increased voltages which tend to produce flashing, as has already been referred to under the subject of flashing when the circuit breaker is opened.

PERIPHERAL SPEED OF COMMUTATOR

This presents two separate limitations in direct-current design, one being largely mechanical and the other being related to voltage conditions. As regards operation, the higher the commutator speed, as a rule, the more difficult it is to maintain good contact between brushes and commutator face. This is not merely a function of speed, but rather of commutator diameter and speed together. Apparently it is easier to maintain good brush contact at 5000 ft. per minute with a commutator 50 in. in diameter than with one of 10 in. in diameter. Very slight unevenness of the commutator surface will make the brushes "jump" at high peripheral speeds, and the larger the diameter of the commutator with a given peripheral speed the less this is.

The peripheral speed of the commutators is also limited by constructive conditions. With the usual V-supported commutators, the longer the commutator the more difficult it is to keep true, especially at very high speeds and the higher temperatures which are liable to accompany such speeds. Therefore, the allowable peripheral speeds are, to some extent, dependent upon the current capacity per brush arm, for the length of the commutator is dependent upon this. At the present time peripheral speeds of about 4500 ft. per minute are not uncommon with commutators carrying 800 to 1000 amperes per brush arm. In the case of 60 cycle, 600 volt synchronous converters, 5200 to 5500 ft. speeds are usual with currents sometimes as high as 500 to 600 amperes per arm. For the small diameter commutators used in direct-current turbo-generator work, peripheral speeds of 5500 to 6000 ft. have been common. However, such machines usually have very long commutators and of the so-called "shrink-ring" construction. With the higher commutator speeds there has come the practice of "truing" commutators *at full speed.*

The other limitation fixed by peripheral speed, namely, that of the voltage, is a more or less indirect one. It is dependent upon the number of commutator bars that are practicable between two adjacent neutral points. The product of the distance between adjacent neutral points and the frequency in alternations gives the peripheral speed of the commutator (distance between neutral points in feet times alternations per minute equals peripheral speed in feet per minute). This then limits the maximum number of commutator bars, and therefore the maximum voltage which is possible, assuming a safe limiting voltage per bar. From this it may be seen that the higher the peripheral speed, the higher the permissible voltage with a given frequency. In the same way, if the frequency can be lowered (either the speed or the number of poles be reduced) the permissible voltage can be increased with a given peripheral speed. Where the speed and the number of poles are definitely fixed and the diameter of commutator is limited by peripheral speed and other conditions, the maximum practicable voltage is thus very definitely fixed. This is a point which apparently has been misunderstood frequently. It explains why in railway motors for high voltages it is usual practice to connect two armatures permanently in series; also, why two 60 cycle synchronous converters are connected in series for 1200 or 1500 volt service. In synchronous converter work, the frequency being fixed once for all, the maximum direct-current voltage is directly dependent upon the peripheral speed of the commutator.

Classification and Nomenclature of Electric Motors

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On account of the confusion existing regarding the nomenclature of alternating-current commutator motors, an attempt at present is being made by a subcommittee of the A.I.E.E. to define definitely a number of terms in use. The principal difficulty is to avoid conflicting with the usage of existing terms which are so well established that no classification, no matter how desirable otherwise, will be able to change the use of these words in actual practice. In view of the close relationship of some commutator motors to other types, it seems advisable to extend the definitions proposed in this article so as to cover, as far as possible, all electric motors known at the present time in order to give a more comprehensive view of the whole situation. This is particularly desirable in view of the fact that the situation has not only been complicated by the commutator motors, but also by the introduction of phase advancers and speed regulating auxiliary machines in connection with induction motors.

Another difficulty, or almost impossibility, encountered in connection with this subject by the A.I.E.E. subcommittee is to find names which are short enough to make their use practicable and at the same time indicate the numerous characteristics of the motor which may be of interest. For this reason it is considered that the best that can be accomplished at the present time is to define certain short terms, each of which refer only to a limited number of characteristics of a certain type or class of motors. With such definitions existing it will be possible to use them either singly or in combination, giving in each individual case only such terms as are of importance or interest in connection with the subject under consideration.

Another fact which has to be considered is that very few motor types are fully in accordance with the definitions given under all conditions of load. A stator-excited commutator motor may, for instance, under certain load conditions receive a relatively small exciting effect from the currents flowing in the armature turns short-circuited by the brushes. Unless such an effect is, however, of great practical importance for the operation of the motor, its existence may well be and should be neglected in naming the motor. In choosing terms for a certain motor it should rather be made a practice to make reference to the essential features purposely introduced into the design, while unavoidable secondary phenomena should usually not be referred to in the name.

It is further to be understood that the use of any one term defined in the following is not to exclude the use of any other term as long as the essential characteristics of a certain motor or motor part are in accordance with the definitions as given.*

1—DEFINITION OF MOTOR PARTS

Before defining terms applying to the various classes of motors it seems advisable to define the meaning of certain terms used for the various parts of the motors, for the various magnetic fields, voltages, currents, energy, etc.

A—PRINCIPAL STRUCTURAL PARTS OF A MOTOR

a—*The Stator* of an electrical machine is the stationary (or non-revolving) part.

b—*The Rotor* of an electrical machine is the rotating part.

Considerable difficulty is experienced in defining the terms armature and field structure so as to make the definition agree with the most common usage of these terms, a change of which seems practically impossible, although it would seem desirable. The following definitions appear to be the best compromise and are assumed to apply wherever the two terms are used later on.

c—*The Armature* of an electrical machine is the member in which under normal operating conditions an e.m.f. is induced by a relative *mechanical* movement between the conductors and a magnetic field.

According to this, a member in which an e.m.f. is induced by a rotating field set up in the same member without a relative mechanical movement between the conductors and the field should not be called an armature. The use of the word armature follows from the above definitions in connection with the various types of machines as given below.

The Armature of a direct-current machine is the member in which the voltages are induced, which is provided with a commutator and is usually the rotor.

The Armature of a synchronous alternating-current machine is the member in which the alternating voltages are induced, which may either be the rotor or the stator.

The Armature of either a squirrel-cage or slip-ring type induction motor in which the secondary is short circuited is the secondary member. Since either the stator or the rotor may be used for the primary member, the armature may be either the stator or the rotor.

The Armature of a slip-ring type induction motor which receives its exciting current in the secondary circuit from an outside source is the primary member, Fig. 43.

Since in some modern induction motors the field exciting currents are partly furnished by the primary and partly by the secondary, both the primary and secondary of such motors may be called an armature according to the above definition. In view of this, and also in view of the fact that the word armature has not been used much in connection with induction motors of the squirrel-cage and slig-ring type in the past, it is

*The terms here given and marked * are at present being considered for definition by the A.I.E.E. subcommittee; those marked ** are part of the Standardization Rules. The definitions are, however, in many cases different from those given by the A.I.E.E. in order to better adapt them for the classification as outlined in this article. Definitions marked † are in line with those proposed by Mr. A. S. McAllister, chairman of the committee. The figure references are to the illustrations which appeared in an article by the writer and Mr. J. V. Dobson in the March, 1910 issue of the Journal and to the appendix to this article.

suggested that the word armature be avoided altogether in connection with such motors.

The Armature of an alternating-current commutator motor is the member in which under normal operating conditions an e.m.f. is induced by a relative mechanical movement between the conductors and the magnetic field. This is in most cases the revolving member or the rotor provided with a commutator. Machines with stationary commutator member are at present of no practical importance.

d—*The Field Structure* (often briefly called the field) of an electrical machine is a member supporting a winding which creates a magnetizing field for the purpose of inducing voltage in an armature by a relative mechanical movement between the field and the armature conductors.

With this definition the use of the words field structure is definitely limited to one member in practically all direct-current machines, in all synchronous alternating-current machines and in alternating-current commutator machines in which the torque field is excited by a winding on the stator. For reasons similar to those given in connection with the armature, either member or both members of an induction motor may be called field structure according to the above definitions, depending upon the case. Similar conditions apply to armature excited commutator motors. For this reason it seems advisable to limit the words field structure in its practical use to direct-current machines, synchronous alternating-current machines and stator excited alternating-current commutator machines.

e—*The Primary Member* (often briefly called the primary) of a motor is the member which receives the major part of the working energy of the motor directly from the power supply.

f—*The Secondary Member* (often briefly called the secondary) of a motor is the member which receives the major part of its working energy through induction or transformer action from the other member.

The fact that a certain member receives a relatively small amount of energy directly from the power supply for exciting, compensating or regulating purposes does not take it out of the class of secondary member, if it receives the major part of its working energy or currents through induction from the other member.

In view of the fact that neither direct-current machines nor alternating-current synchronous machines have a secondary member, also, because it is most customary to use the terms armature and stator in connection with alternating-current commutator motors, it is recommended to use the terms primary and secondary member preferably in connection with induction motors only, as has been customary in the past.

g—*The Slip Rings* of an electrical machine are sliding contacts for the purpose of transmitting currents from a revolving member to stationary conductors without changing the electrical characteristics of the current.

h—*The Commutator* of an electrical machine is a member composed of sliding contacts for the purpose of transmitting currents from rotating conductors to stationary conductors and for commutating at the same time the currents in the conductors connected to the commutator contacts.

i—*The Brushes* of an electrical machine are sliding contact members, working in conjunction with slip rings or commutators.

j—*The Core* of an electrical machine is a part made of magnetic material for the purpose of carrying useful magnetic fluxes.

k—*The Windings* of an electrical machine are conductors on either the stator or the rotor of a machine carrying useful currents.

B—ELECTRICAL TERMS

a—*A Working Current* of an electrical machine is a current or its component producing a working torque in conjunction with the main magnetic field.

b—*The Load Current* of an electrical machine is a current changing with the mechanical load of the machine.

c—*An Exciting Current* of an electrical machine is a current or component thereof that is in phase (positive or negative direction) with a magnetic field excited by such a current.

d—*The Energy Voltage* of an electrical machine is a voltage in phase with a working current.

e—*The Working Voltage* of an electric motor is that part of the energy voltage which is impressed upon a winding either by conduction or induction (transformer action) to be used up in the transformation of electrical energy to mechanical energy within the motor.

f—*The Working Energy* in a motor is the product of a torque producing current flowing in a motor winding and an e.m.f. impressed upon the same winding, either by conduction or induction (transformer action), to be used up in the transformation of electrical to mechanical energy within the motor.

C—MAGNETIC TERMS

a—*The Main or Torque Field* of an electrical machine is the field which, together with the armature working current, produces the working torque.

In direct-current motors and single-phase commutator motors, the axis of the main or torque field is usually at right angle to the axis of the brushes carrying the armature working current. In all polyphase alternating-current motors the torque field is usually rotating. In single-phase synchronous machines the torque field is stationary with revolving armature machines and it rotates with the field structure in revolving field machines.

b—*The Cross Field* of an electrical machine is a field shifted 90 electrical degrees in space against the axis of the torque field.

A definite distinction between torque field and cross field is, of course, usually possible with direct-current machines and single-phase alternating-current machines only; especially with single-phase commutator motors the use of the two terms is very convenient.

c—*The Commutating Field* of an electrical machine is a field introduced for the purposes of favorably affecting the commutation.

In direct-current machines and single-phase commutator machines a commutating field affecting the working brushes is usually a cross field, while a commutating field affecting the exciter brushes is often in line with the main or torque field.

d—*An Armature Field* of an electrical machine is a field produced by currents flowing in the armature.

e—*An Armature Cross Field* of an electrical machine is a cross field produced by currents (usually working currents) flowing in the armature.

f—*The Armature Main Field or Torque Field* of an electrical machine is the main field or torque field produced by currents flowing in the armature.

g—*A Local Cross Field* is a field which extends over a limited part of the pole face only and usually covers approximately the commutating zone (Figs. 34 and 35).

h—*A Local Commutating Field* is a commutating field which extends approximately over the commutating zone only (Figs. 34 and 35).

D—TERMS REFERRING TO THE DETAIL STRUCTURE AND FUNCTION OF MOTOR PARTS

The use of the following terms is convenient in connection with certain classes of motors:—

a—*The Working Brushes* of an electrical machine are brushes carrying principally currents producing the working torque of a machine (Figs. 6 to 41).

b—*The Exciting Brushes* of an electrical machine are brushes carrying principally currents for the purpose of exciting the torque or main field (Figs. 37 to 41).

In many machines, especially those of the polyphase commutating type certain brushes will, of course, serve both purposes. The distinction made above is, however, very useful and convenient for the discussion of many single-phase commutating motors.

c—*A Concentrated Winding* is one in which all turns of the winding for each pole are concentrated in a single coil.

d—*A Distributed Winding* is one in which the turns for each pole are distributed over several slots or recesses, either over the entire pole face (completely distributed winding) or over part of the same (partially distributed winding).

e—*A Short-Circuited Winding* is one which is short-circuited within itself and has no external voltage impressed and no impedance external to the winding proper in circuit, except the relatively small impedance incident to leads, brushes, contact resistance, etc.

f—*A Squirrel-Cage Winding* is one consisting of a number of single conductors connected electrically to each other at both ends.

g—*A Neutralizing Winding* is a winding carrying currents for the purpose of neutralizing the magnetic effect set up by currents in another winding, usually the armature.

There are, of course, quite a number of convenient combination terms, like the following, the definition of which, however, is so self-evident from those previously given that it seems unnecessary to define them here:—Slip-ring rotor; short-circuited rotor; squirrel-cage rotor; stationary armature; revolving armature; stationary field; revolving field; stationary primary; revolving primary; stationary secondary; revolving secondary; stator core; rotor core; stator windings; rotor windings, etc.

MOTOR CLASSIFICATION

The motors themselves may, and should, properly be classified and defined from a number of different viewpoints as indicated in the main headings *2* to *11*, inclusive, as given herewith. Under each of these headings an attempt is made to give under *A* what the writer considers to be the most important and fundamental classification; under *B* certain desirable subclassifications; under *C* whatever alternate classifications, terms and definitions may be used; and under *D* terms and definitions which are convenient in practice and are of a limited scope.

2—CLASSIFICATION WITH RESPECT TO KIND OF ENERGY USED FOR OPERATING THE MOTORS

A—FUNDAMENTAL CLASSIFICATION

a—*A Direct-Current Motor* is one which derives its working energy from a direct-current power supply.

b—*An Alternating-Current Motor* is one which derives its working energy from an alternating-current power supply.

Similar definitions may, of course, be made for such terms as pulsating-current** motor and continuous-current** motor.

B—SUBCLASSIFICATION

c—*A Single-Phase Motor** is one that receives the whole of its working energy from only one phase of an alternating-current supply. It may receive its exciting energy from the same or from another phase† (Figs. 6 to 41, inclusive).

d—*A Polyphase Motor** is one that receives its working energy from a plurality of phases of an alternating-current supply† (Figs. 42 to 44, inclusive).

It will be noticed that all of the above classifications define the motor with regard to the power supply for the working energy of the motor only. The fact that a motor is excited by some other kind of current or from a different phase does not alter the use of any of the above terms.

3—CLASSIFICATION REGARDING METHOD OF CONVEYING OR FEEDING ENERGY INTO THE MOTOR

A—FUNDAMENTAL CLASSIFICATION

Since all motors have at least one rotor and one stator the working energy may be fed into a rotor or a stator, or into both. Accordingly, we have the following fundamental definitions:—

a—*A Rotor Fed Motor* is one in which the working energy is fed into the rotor by applying the energy voltage of the power supply to the rotor.

According to this definition, all of the following motor types are rotor fed:—All direct-current motors; all revolving armature synchronous machines; all slip-ring induction motors with the slip rings connected to the main power supply; and alternating-current commutator motors whose armature circuit is connected to the supply circuit voltage (see Figs. 6, 7, 11, 15, 19, 23, 27, 28, 34, 35 and 36).

b—*A Stator Fed Motor* is one in which the working energy is fed into the stator by applying the energy voltage of the power supply to the stator.

According to this definition, all of the following motor types are stator fed:—All revolving field synchronous machines; all slip-ring and squirrel-cage induction motors with the stator connected to the main power supply, as in Figs. 43 and 44, and alternating-current commutator motors in which the circuit containing the stator cross field winding is connected to the supply circuit voltage (see, for instance, Figs. 8, 12, 16, 20, 24, 29, 37, 38 and 41).

c—*A Doubly Fed Motor** is one in which the working current is fed into the motor by applying energy voltage of the power supply to both the stator and the rotor.

According to this definition, all the following motors are doubly fed:—Alternating-current commutator motors with two circuits, one containing the armature and one a cross field winding, and both of these circuits receiving an energy voltage from the power supply, as in Figs. 9, 10, 13, 14, 17, 18, 21, 22, 25, 26, 30, 31, 32, 33, 39 and 40; slip-ring induction motors

working in conjunction with a regulating machine in the secondary, as shown in Fig. 44; and many polyphase commutator motors, as, for instance, that shown in Fig. 42.

B—SUBCLASSIFICATION

With doubly fed motors it is possible to supply the two members with energy in the same direction so that an addition of energy is obtained; it is also possible to supply the two members with working energy in the opposite direction so that one member receives a surplus of energy which is returned to the line by the other member which, therefore, really acts as a generator member. Accordingly, the following subclassifications should be made:—

d—*An Additionally (Doubly) Fed Motor* is one in which the working energy is fed into the motor by applying energy voltage to both the stator and the rotor so that the resultant working energy is equal to the sum of the two components.

This definition covers alternating-current commutator motors in which the voltage is impressed upon the two members in the same direction (see, for instance, Figs. 9, 13, 17, 21, 25, 30, 32 and 33), as well as slip-ring induction motors working above synchronous speed in conjunction with a regulating machine in the secondary (Fig. 44).

e—*A Differentially (Doubly) Fed Motor* is one in which the working energy is fed into the motor by applying energy voltage to both the stator and the rotor so that a resultant working energy is equal to the difference of the two components.

This definition covers alternating-current commutator motors in which the voltage is impressed upon the two members in opposite direction (see, for instance, Figs. 10, 14, 18, 22, 26 and 31), as well as slip-ring induction motors working below synchronous speed in conjunction with a regulating machine in the secondary (Fig. 44).

C—ALTERNATE CLASSIFICATIONS

Instead of classifying the method of power supply according to rotor or stator, the classification may be made as to whether working energy is supplied to only one member by conduction or as to whether the working energy is transmitted from one member to the other by induction or transformer action within the motor. This classification naturally suggests the following terms:—

f—*A Conduction Motor** is one in which working energy is supplied to only one of the members and conveyed to it by conduction.

This definition covers all direct-current motors, all synchronous alternating-current motors, and single-phase commutator motors in which only the armature circuit is connected to the supply circuit voltage (see, for instance, Figs. 6, 7, 11, 15, 19, 23, 27, 28, 34, 35 and 36).

g—*An Induction** or Transformer Motor** is one in which the working energy is transmitted from one of the members to the other member by electromagnetic induction or transformer action.

This definition covers all squirrel-cage and slip-ring type induction motors and alternating-current commutator motors in which working energy is transmitted from one member to the other by transformer action. While, according to the above general and broad definition, the term induction motor is applicable to commutator motors, this term has for many years been used principally for induction motors of the squirrel-cage and slip-ring types. It seems, therefore, advisable to continue the use of the term induction motor for motors of the slip-ring and squirrel-cage type only. The term transformer motor is recommended for use in connection with commutator motors only.

D—TERMS OF A LIMITED SCOPE

According to the convention proposed under C, g with regard to limiting the scope of the words induction and transformer motor, the following definitions may be proposed:—

h—The term *Induction Motor***, if used without modifying terms, usually means a motor in which non-commutated working currents are flowing in both members and in which working energy is transmitted from one of the members to the other by electromagnetic induction.

The term induction motor applies, therefore, to motors generally known as slip-ring induction motors and squirrel-cage (induction) motors.

i—The term *Transformer Motor** if used without modifying terms means usually a motor in which commutated working currents are flowing in the circuit of one of the members and in which working energy is transmitted from one member to the other by transformer action.

The term transformer motor applies, therefore, usually to stator fed commutator motors (see, for instance, Figs. 8, 12, 16, 20, 24, 29, 37, 38 and 41). In order to take care of a certain class of motors which have commutated and non-commutated currents flowing in one of the members by having, for instance, resistance in parallel to coils connected to a commutator or by having a commutated and non-commutated winding in the motor, the following definition might be suggested:—

j—*A Double Wave Induction Motor* is one in which the circuits of one member carry both commutated and non-commutated currents and in which working energy is transmitted from one member to the other by electromagnetic induction.

The name double wave induction motor suggests itself because the action of two alternating-currents of different wave length is operating the motor.

k—*An Armature Fed Motor** is one in which the working current is fed into the armature by applying the energy voltage of the power supply to the armature.

Since the word armature is not to be applied to induction motors, and since synchronous motors and direct-current motors are always armature fed, it is recommended that the term armature fed is preferably applied to alternating-current commutator motors only. For similar reasons it seems advisable to apply the term conduction motor usually to alternating-current commutator motors only, such as those in Figs. 6, 7, 11, 15, 19, 23, 27, 28, 34, 35 and 36.

The following terms also seem to be well adopted to designate certain special classes of motors rather definitely:—

l—*A Commutator Fed Motor* is one in which the working current is fed into the armature by applying the energy voltage of the power supply to the brushes of a commutator.

It is evident that a commutator fed motor and armature fed motor are practically identical.

m—*A Cross Field Fed Motor* is a single-phase commutator motor in which the working energy is fed into the cross field winding circuit by applying the energy voltage of the power supply to the circuit containing the cross field winding.

This term is naturally limited in practice to single-phase motors because polyphase motors have no definite cross field winding.

n—*A Reverse Doubly Fed Motor* is a commutator motor in which the working energy is fed into the motor by applying energy voltage to both the stator and the rotor so that the resultant working energy is equal to the difference of the two components.

This expression seems convenient to designate differentially fed motors of the commutator type having two circuits, since with these motors the differential feeding is obtained by reversing one of the circuits.

o—*A Neutralized Motor** is one in which use is made of a winding for producing a magnetomotive-force opposed in space and time to the armature cross field magnetomotive-force over practically the entire pole face.

This term applies to both alternating-current and direct-current commutator motors having a distributed neutralizing (previously called at times compensating) winding. If motors have a neutralizing winding covering only part of the pole face, as is the case with many commutating pole motors, they should be called partially neutralized motors.

p—A motor with *Conductive Neutralization* or a *Series Fed Motor* is one in which the stator cross field winding is connected in series with the armature in a single circuit (see, for instance, Figs. 6, 27, 34, 35 and 36).

q—A motor with *Inductive Neutralization* is one in which neutralizing currents are caused to flow in a cross field winding by transformer action (as in Figs. 7, 11, 15, 19, 23 and 28).

Cross field fed motors have in the past been called at times "repulsion motors."* Since there is considerable disagreement, however, as to just what a repulsion motor is, it is recommended that this term be avoided, at least until a certain definition has been adopted by the A.I.E.E. With the definitions previously given it is possible to designate any known type of motor without resorting to the terms repulsion motor or series repulsion motor.

4—CLASSIFICATION WITH REGARD TO KIND OF ENERGY USED FOR EXCITING THE MAIN FIELD

A—FUNDAMENTAL CLASSIFICATION

a—*A Direct-Current Excited Motor* is one in which the torque field is excited by direct current.

b—*An Alternating-Current Excited Motor* is one in which the torque field is excited by alternating current.

B—SUBCLASSIFICATION

c—*A Line Frequency Excited Motor* is one in which the torque field is excited by currents of the line frequency.

d—*A Low Frequency Excited Motor* is one in which the torque field is excited by currents of a frequency lower than the line frequency.

The above classification is of some practical importance in combination with alternating-current motors in so far as it indicates the k.v.a. which are to be supplied for the purpose of excitation, and which are the smallest with direct-current excitation (synchronous motors), somewhat larger with low-frequency excitation (induction motor with a phase advancer or exciter connected in the secondary, as for instance in Figs. 43 and 44), and the largest with line frequency excitation (straight induction motors without auxiliary machines, and in all alternating-current commutator motors).

5—CLASSIFICATION WITH REGARD TO THE MEMBER CARRYING THE MAGNETIZING CURRENTS FOR THE TORQUE FIELD

A—FUNDAMENTAL CLASSIFICATION

Since any motor has at least one stator and one rotor, the following possibilities exist, namely, the currents exciting the main or torque field may be flowing in the stator, rotor, or both. Accordingly, we have the following definitions:—

a—*A Rotor Excited Motor** is one in which the torque producing field is due to current in a winding located on the rotor.†

The following motors are, therefore, rotor excited:—Synchronous motors with revolving field; standard induction motors with the rotor connected to the line; induction motors with the rotor serving as secondary and excited by a phase advancer (Figs. 43 and 44); all armature excited commutator motors (Figs. 37, 38, 39 and 40).

b—*A Stator Excited Motor** is one in which the torque producing field is due to currents in a winding located on the stator†.

The following motors are, therefore, stator excited:—All direct-current machines of common construction; synchronous motors with revolving armature; all standard induction motors with the stator connected to the line, and induction motors in which the stator is the secondary and excited by a phase advancer; all stator excited commutator motors (see, for instance, Figs. 6 to 36, inclusive).

c—*A Doubly Excited Motor** is one in which the torque producing field is due to current in windings located on the stator and on the rotor (as in Fig. 41).

B—SUBCLASSIFICATION

d—*An Additionally Doubly Excited Motor* is one in which the torque producing field is due to the sum of exciting currents flowing in windings located on the stator and rotor.

e—*A Differentially Doubly Excited Motor* is one in which the torque producing field is due to the difference of exciting currents flowing in windings located on the stator and rotor.

D—TERMS OF LIMITED SCOPE

f—*A Primary Excited Motor* is one in which the torque producing field is due to currents in a winding located on the primary member.

g—*A Secondary Excited Motor* is one in which the torque producing field is due to currents in a winding located on the secondary member (as in Figs. 43 and 44).

For reasons previously given, the above two terms should be used principally in connection with induction motors.

h—*An Armature Excited Motor* is one in which the torque producing field is due to currents in a winding located on the armature (as in Figs. 37, 38, 39 and 40).

i—*A Commutator Excited Motor* is one in which the torque producing field is due to currents passing through a commutator into the armature (as in Figs. 37, 38, 39 and 40).

For reasons previously given, the last two terms should be used principally in connection with commutator motors.

6—CLASSIFICATION WITH REGARD TO SOURCE OF EXCITING CURRENTS

A—FUNDAMENTAL CLASSIFICATION

a—*A Line Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are furnished

by the line furnishing the working energy of the motor.

Such motors are most direct-current motors, induction motors without a phase advancer and most stator excited alternating-current commutator motors, as in Figs. 6 to 31 and 33 to 35.

b—*A Self-Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are generated within the motor.

Such motors are most armature excited commutator motors, as shown in Figs. 37 to 41.

c—*A Separately Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are supplied by a current source different from that supplying the working energy and different from the motor itself.

Such motors are direct-current motors and alternating-current motors excited by either a battery or separate exciter, as in Figs. 32, 36, 43 and 44.

d—*A Transformer Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are supplied by a transformer winding different from that supplying the working energy of the motor (Figs. 27 to 31, 33 and 40).

e—*A Phase Converter Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are supplied by a phase converter.

Such motors are stator excited, single-phase commutator motors, the field of which is excited by a phase converter, usually for the purpose of regeneration, as shown in Fig. 36.

f—*A Frequency Converter Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are supplied by a frequency converter.

Such motors are induction motors, the secondary of which is connected to a frequency changer serving as a regulating machine and furnishing exciting current, as in Fig. 44.

g—*A Resultant Excited Motor* is one in which the exciting kilo-volt amperes for the torque field are the resultant of the kilo-volt amperes furnished by two or more different sources of exciting kilo-volt amperes (as in Fig. 42).

B—SUBCLASSIFICATION

All motors which are excited from a source other than the line may be either fully excited by this other source or over-excited or under-excited. Accordingly, we obtain the following subclassification:—

h—*An Under-Excited Motor* is one which receives part of the exciting kilo-volt amperes for the torque field from a source other than the energy power supply.

In case of alternating currents, such motors are usually partly power-factor compensating.

i—*An Over-Excited Motor* is one which receives exciting kilo-volt amperes for the torque field from a source other than energy power supply, in excess of the kilo-volt amperes needed for the excitation of the torque field.

In case of alternating currents, such motors are usually either fully power-factor compensated or over-compensated, which means that they run with leading power-factor.

7—CLASSIFICATION WITH REGARD TO THE DEPENDENCY OF THE TORQUE FIELD UPON THE LOAD OF THE MOTOR

A—FUNDAMENTAL CLASSIFICATION

a—*A Load Excited Motor* is one in which the exciting current of the torque field is about proportional to the load current.

Such motors are all series excited direct-current motors and all load excited alternating-current commutator motors (see, for instance, Figs. 6 to 31, inclusive, and 33, 34, 35, 38, 40 and 42).

b—*A No-Load Excited Motor* is one in which an exciting current for the torque field exists with no load on the motor and in which the exciting ampere turns are not materially dependent upon the load.

Such motors are direct-current shunt motors; all synchronous motors; most induction motors; most separately excited motors of all kinds and many self-excited motors of the alternating-current commutator type (Figs. 37, 39 and 41).

c—*A Compound (Excited) Motor* is one in which an exciting current for the torque field exists with no load on the motor, but in which the exciting ampere turns are materially changed with changing load.

B—SUBCLASSIFICATION

d—*A Positive or Cumulative Compound (Excited) Motor* is one in which an exciting current for the torque field exists with no load on the motor and in which this exciting field increases with increased load.

e—*A Differential Compound (Excited) Motor* is one in which an exciting current for the torque field exists with no load on the motor and in which this exciting field is decreased with increased load.

C—ALTERNATIVE TERMS

f—*A Constant Field Motor** is one in which the torque-producing field remains practically constant independent of the load.†

Such a motor will in general have a constant speed characteristic similar to that of the direct-current shunt motor.

g—*A Variable Field Motor** is one in which the torque-producing field varies in some proportion with the load current.

Such a motor will in general have a load speed characteristic similar to those of direct-current series and compound motor.

D—TERMS OF LIMITED SCOPE

h—*A Series Excited Motor* (often briefly called series motor) is one in which the torque field is excited by the armature load current or working current.

Such motors are the well-known series direct-current motors and a number of alternating-current commutator motors (see, for instance, Figs. 6 to 10, inclusive, and 34, 35 and 42).

i—*A Cross Field Excited Motor* is one in which the torque field is excited by the current flowing in a cross field winding.

In practice this definition is limited to single-phase commutator motors with the cross field and main field winding connected in series (see, for instance, Figs. 11 to 18, inclusive, and 38).

j—*A Shunt Excited Motor* (often briefly called shunt motor) is one in which the torque field is connected in parallel to a winding carrying the working energy, usually the armature.

8—CLASSIFICATION REGARDING THE SPEED CHARACTERISTICS OF THE MOTOR

A—FUNDAMENTAL CLASSIFICATION

a—*A Motor with Load Characteristic* is one in which the excitation of the torque field winding is essentially

proportional to the load current. This means that, as a rule, the motor will have a tendency to run away at no-load and that the speed curve will be concave upwards. (Figs. 6 to 31, 33, 34, 35, 38, 40 and 42).

b—*A Motor with Limited Speed Characteristic* is one in which the excitation of the torque field has, even at no load, a definite value in phase with the armature no-load current so that the motor speed at no-load is definitely limited. (Figs. 32, 36, 37, 39, 41, 43 and 44).

It is evident that the words load characteristic corresponds to what has frequently been called series characteristic in the past, while the words limited speed characteristic corresponds to what has frequently been called shunt and compound characteristic. The above suggested definitions are, however, of advantage in so far as they broadly cover all motors, including all combinations possible with alternating-current commutator motors.

c—*A Motor with Constant Speed Characteristic*** is one in which the speed is either constant or does not materially vary between no-load and the rated load. (Figs. 32, 36, 37, 39, 41, 43 and 44).

It may be advisable to definitely limit the speed variation between the two loads to about 10 to 20 percent in combination with this term.

d—*A Motor with Compound Characteristic* is one the speed of which is definitely limited at no-load, but varies materially with the load.

C—ALTERNATIVE CLASSIFICATION

Instead of classifying motors with regard to the character of the speed curve, alternating-current motors may also be classified with regard to the relation of their speed to the frequency and number of poles. We may classify as follows:—

e—*A Synchronous Motor* is one in which there is for all normal loads a constant positively fixed relation between the motor speed, the frequency of the power supply and the number of poles in the motor.

f—*A Non-Synchronous or Asynchronous Motor* is one in which the relation between the motor speed, the frequency of the power supply and the number of poles in the motor is not positively maintained constant for normal loads.

g—*A Relative Synchronous Motor* is one in which currents of two usually different frequencies are supplied to the two members of the motor and in which there is for all normal loads a positively fixed relation between the motor speed, the difference or sum of the two frequencies and the number of poles in the motor.

Motors of the latter class are usually induction motors connected with their secondary to a regulating machine which supplies lower frequency (Fig. 44).

9—CLASSIFICATION REGARDING THE COMMUTATING FIELD OF A MOTOR

A—FUNDAMENTAL CLASSIFICATION

a—*A Commutating Field Motor* is one which has a field for the purpose of improving the commutation (Figs. 8, 9, 10, 12, 13, 14, 34, 35, 37 to 40, 41 and others).

b—*A Non-Commutating Field Motor* is one which has no field for the purpose of improving the commutation.

B—SUBCLASSIFICATION

c—*A Motor with Commutating Field Extending Over the Entire Pole Area* is usually a motor with a distributed commutating field winding, distributed over the entire pole area (Figs. 8, 9, 10, 12, 13, 14, 37 to 41).

d—*A Motor with Local Commutating Field* is usually a motor with a commutating field extending over the commutating zone only (the field winding may be in this case concentrated or partly distributed—Figs. 34 and 35).

e—*A Motor with Commutating Poles* is usually a motor with a local concentrated commutating pole winding.

C—ALTERNATIVE CLASSIFICATION

Instead of classifying the motors with regard to the extent and nature of the commutating field, it is possible to classify with regard to the connection of the commutating field winding. The commutating field winding may be series connected or shunt connected to some motor winding carrying working energy. Outside of this a great many combination connections may be used, especially in connection with alternating-current commutator motors. As a rule, it will not be possible to give the connection of the interpole in a brief term and it is, therefore, general practice to briefly describe the connection of the interpole winding.

At times motors with commutating fields have been called compensated motors. The term compensated motor is, however, rather undesirable, as it may refer to a number of different things which may be compensated for. It is, therefore, desirable to always use it only in connection with other terms, as, for instance:—

f—*A Motor Compensated for Commutation* is one in which means other than a pure neutralizing winding are provided for improving the commutation.

10—CLASSIFICATION REGARDING POWER-FACTOR COMPENSATION

A—FUNDAMENTAL CLASSIFICATION

a—*A Power-Factor Compensated Motor* is one in which means other than a neutralizing winding are used for improving the power-factor of an alternating-current motor.

b—*A Motor not Compensated for Power-Factor* is one in which no means other than a neutralizing winding are used for improving the power-factor of an alternating-current motor.

Self-excited commutator motors and separately excited commutator and induction motors, as well as synchronous motors, can usually be power-factor compensated (Figs. 36 to 44).

B—SUBCLASSIFICATION

c—*A Power-Factor Under-Compensated Motor* is one in which means are used for improving the power-factor, but in which a lagging power-factor below unity is obtained.

d—*A Power-Factor Fully Compensated Motor* is one in which means are used for improving the power-factor so as to give a power-factor of practically unity.

e—*A Power-Factor Over-Compensated Motor* is one in which means are used for improving the power-factor to such an extent as to obtain a leading power-factor below unity.

C—ALTERNATIVE TERMS

In place of the words power-factor compensated motor the term power-factor advanced motor is used at times; the same definition may be applied to this term.

11—CLASSIFICATION REFERRING TO ESSENTIAL STRUCTURAL FEATURES OF A MOTOR

Among practical men and even those fully familiar with the working characteristics of electric motors, it is quite customary and often very convenient to designate motors with names referring to essential structural features. Thus the words, "Commutator Motor," "Slip-Ring Motor," "Squirrel-Cage Motor," as referring to motors having a commutator, slip rings or a squirrel cage, respectively, are used very commonly and are in a good many cases quite sufficient. The definitions of these terms are, of course, self-evident.

APPENDIX

The following motor types have not been so commonly used in this country as to be familiar to everybody. The titles are in line with the definitions of this article. The terms given in large type are all that would be needed as a rule; the terms given below, while applying to the motors, are usually found in motors designated by the main title given and need, therefore, not be mentioned unless it is desirable to call special attention to a certain feature. It will be seen that the main title is in most cases reasonably short and indicative of all essential features of the motor. It requires, of course, some familiarity with the working principles of the motors to recognize the full meaning of a few terms, but it would surely be expecting too much to expect a brief nomenclature to indicate the full working theory of a motor to one not familiar with the particular field.

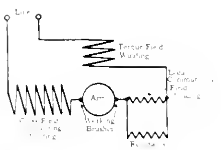

FIG. 34—SERIES STATOR EXCITED CONDUCTION MOTOR, WITH LOCAL SERIES COMMUTATING WINDING CONNECTED IN PARALLEL TO A RESISTANCE AND WITH CONDUCTIVE NEUTRALIZING WINDING

This means that the motor is at the same time: an armature, commutator and rotor fed motor, line frequency excited, line excited, load speed characteristic, non-synchronous, commutating field and commutator motor.

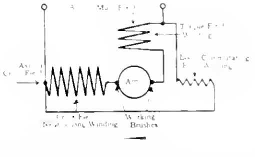

FIG. 35—SERIES STATOR EXCITED CONDUCTION MOTOR, WITH SHUNT CONNECTED LOCAL COMMUTATING WINDING AND CONDUCTIVE NEUTRALIZING WINDING

This name means, as a rule, that the motor is at the same time: an armature, commutator and rotor fed motor, line frequency excited, line excited, load speed characteristic, non-synchronous, commutating field and commutator motor.

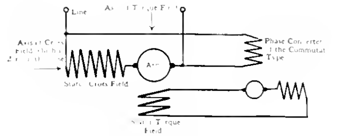

FIG. 36—SERIES FED PHASE CONVERTER EXCITED MOTOR OR PHASE CONVERTER EXCITED CONDUCTION MOTOR

This name means, as a rule, that the motor is at the same time: a single-phase, armature and rotor fed, stator excited, line frequency excited, separately excited, limited speed characteristic, non-synchronous, non-commutating field, conductively neutralized, commutator motor.

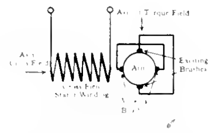

FIG. 37—SINGLE-PHASE TRANSFORMER MOTOR (NO-LOAD SELF-EXCITED) OR CROSS FIELD FED MOTOR (NO-LOAD COMMUTATOR EXCITED)

Either of these names mean, as a rule, that the motor is at the same time: a single-phase, stator fed, armature and commutator excited, line frequency excited, limited speed characteristic, non-synchronous, commutating field, power-factor compensated, self-excited and commutator motor.

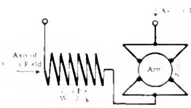

FIG. 38—SINGLE-PHASE TRANSFORMER MOTOR (LOAD SELF-EXCITED) OR CROSS FIELD FED MOTOR (LOAD COMMUTATOR EXCITED)

Either of these names mean, as a rule, that the motor is at the same time: a single-phase, stator fed, armature and commutator excited, line frequency excited, load speed characteristic, non-synchronous, commutating field, power-factor compensated, self-excited and commutator motor. All brushes serve in this case as working and exciting brushes as well; the exciting current flows from brushes *a* to *c* and from *b* to *d*; the working current from *a* to *b* and from *c* to *d*.

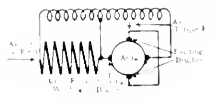

FIG. 39—DOUBLY FED, SINGLE-PHASE, COMMUTATOR MOTOR (NO-LOAD SELF-EXCITED)

This name means, as a rule, that the motor is at the same time: an armature and commutator excited, line frequency excited, limited speed characteristic, non-synchronous, commutating field, and power-factor compensated motor.

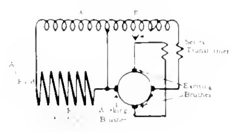

FIG. 40—DOUBLE FED, SINGLE-PHASE, COMMUTATOR MOTOR (LOAD SELF-EXCITED)

This name means, as a rule, that the motor is at the same time: an armature and commutator excited, line frequency excited, load speed characteristic, resultant excited, non-synchronous, commutating field and power-factor compensated motor.

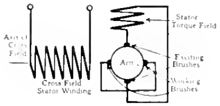

FIG. 41—SINGLE-PHASE, DOUBLY SELF-EXCITED, TRANSFORMER MOTOR (NO-LOAD EXCITED) OR CROSS-FIELD FED, DOUBLY SELF-EXCITED MOTOR (NO-LOAD EXCITED)

Either of these names mean, as a rule, that the motor is at the same time: a single-phase, stator fed, line frequency excited, limited speed characteristic, non-synchronous, commutating field, power-factor compensated, self-excited and commutator motor.

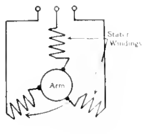

FIG. 42—POLYPHASE (THREE-PHASE) DOUBLY FED SERIES (EXCITED) MOTOR

This name means that the motor is at the same time: differentially doubly fed at under-synchronous speed, stator fed near synchronous speed and additionally doubly fed at over-synchronous speed, doubly excited, resultant line and self-excited, line frequency excited, load speed characteristic, non-synchronous, power-factor compensated and commutator motor. The brushes are working brushes and exciting brushes.

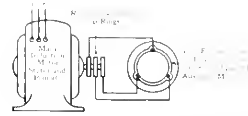

FIG. 43—POWER-FACTOR COMPENSATED INDUCTION MOTOR OR SECONDARY EXCITED INDUCTION MOTOR

Either of these names mean, as a rule, that the motor is at the same time: a polyphase (it is customary to state single-phase induction motor when the motor is single-phase), stator fed (rotor fed induction motors are so rare that it is usually stated when the motor is rotor fed), secondary excited, low frequency excited, limited speed characteristic, non-synchronous, power-factor compensated, separately excited, and slip-ring motor.

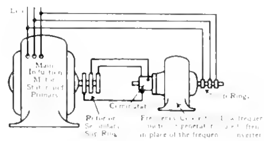

FIG. 44—RELATIVELY SYNCHRONOUS INDUCTION MOTOR (SECONDARY FREQUENCY CONVERTER EXCITED) OR INDUCTION MOTOR WITH AUXILIARY REGULATING MACHINE

Either of these names usually means that the motor is at the same time: a polyphase, stator fed, secondary excited, low frequency excited, limited speed characteristic, power-factor compensated, separately excited, slip-ring motor and adjustable speed motor.**

Adapting Direct-Current Motors to Changed Conditions

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It is frequently desirable to change a direct-current motor so that it may be operated under different conditions, for instance, at a speed other than the rated one, at a different voltage, or with changes in its characteristics, such as regulation, etc. The problem of operating a motor as a generator also presents itself. Many of these changes may be made in the field with very little trouble and expense. The general theory encountered in considering the usual changes is relatively simple.

First consider some fundamental principles in the operation of a direct-current generator. The field poles supply a stationary magnetic field, which is cut by the conductors on the revolving armature, and causes an e.m.f. to be generated in them, which is directly proportional to the magnetic flux and the rate of cutting. This e.m.f. causes a current to flow through the armature and the external circuit. Whenever a current flows through a conductor in a magnetic field, a force is exerted tending to move it to one side or the other, depending upon the direction in which the current is flowing, relative to the flux. This force is directly proportional to the flux and the current flowing. When conductors in the slots of an armature are acted upon by such a force, a turning moment or torque is produced. In a generator the current flows in the same direction as the e.m.f. generated by the armature. Due to this direction of flow, a torque is produced which opposes rotation; thus external power is required to drive the armature and overcome this force. Since the current flows in the same direction as the generator e.m.f., the internal resistance drop opposes the flow, thus the terminal e.m.f. is equal to the generated e.m.f. minus the resistance drop. In the case of a motor the line e.m.f. drives the current through the armature, and thus a torque is produced which causes rotation. As soon as the armature rotates, an e.m.f. is generated in the same way as that produced in a generator. In this case the e.m.f. opposes the flow of current. Stability is reached when the difference between the generated voltage or counter e.m.f. and the applied e.m.f. is just sufficient to allow a current which will produce the required torque to flow through the internal resistance. In other words, internal resistance drop plus the counter e.m.f. always equals the applied e.m.f. The following equations show the above very clearly:—

In a generator, $E = \frac{W_s p \phi R_m}{60 \times 10^8} - IR_1$ ... (1)

In a motor, $R_m = \frac{(E - IR_1) 10^8 \times 60}{W_s p \phi}$ ......(2)

Where E = Terminal e.m.f.
I = Armature current.
R_1 = Resistance of armature, commutating and series coils.
W_s = Series conductors on the armature.
p = Number of poles.
ϕ = Magnetic flux issuing from one pole, in kilo-lines per sq. in.
R_m = R.p.m.

The function of the field coils, both the shunt and series, is to supply the magnetizing force necessary to produce the required flux. This magnetizing force is directly proportional to the combined ampere-turns of the exciting coils, which are determined by the current flowing in one turn, multiplied by the number of turns in the coil. (The result is the same whether it be a small current and a large number of turns, or vice versa). The magnetizing force is made up of two parts, by far the larger being that required to drive the flux across the air-gap. This part varies directly as the flux and the equivalent air-gap length: being a direct function, it is plotted as a straight line, as shown for two different lengths of air-gap in Fig. 1. The magnetizing force for the iron part of the circuit follows no direct law, but depends on the magnetic density and material. It is represented in Fig. 1 as added to the air-gap line, giving the solid curved line, or the no-load saturation curve. When operating under load, the armature teeth and pole tips become more or less saturated, due to armature reaction, and the flux is slightly reduced. To get a general idea of the effect of changing the air-gap on the flux and excitation consider the relation expressed in Fig. 1. With a one-fourth inch air-gap a magnetizing force of *oa* ampere turns will be required to produce the flux ϕ_1, while with a one-eighth inch gap, only *ob* ampere turns will be needed to produce the same flux. Again, keeping the excitation constant and equal to *oa* ampere turns, a one-eighth inch air-gap will give a flux equal to ϕ_2.

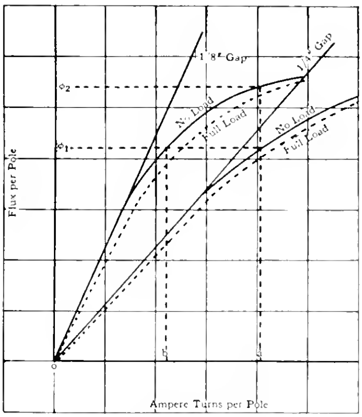

FIG. 1—TYPICAL MAGNETIZATION CURVES

It is obvious that for a given motor operating at any given load, equation (2) reduces to:—

$$R_m = \left[\frac{(E-IR_1)\,10^8 \times 60}{W_s\, p}\right] \times \frac{1}{\phi} = \frac{K}{\phi}$$

By this equation the flux for any given field excitation can be reduced to speed, and plotted as such against field ampere turns. This gives the curves in Fig. 2, which are better adapted for showing the relations of speed and regulation. These curves may readily be taken by test, and are known as the shunt regulation curves. From the equation one would naturally expect the full-load curve to fall below the no-load. It may or may not, depending upon the relation between the resistance drop in the motor and the reduction in the flux due to armature reaction. Usually the full-load curve is the higher, as in Fig. 2, except in high voltage, or small size machines, where it may coincide or fall lower.

By inspection of Fig. 2 it will be obvious that the speed can be changed by varying the field excitation, or by changing the air-gap length, or both. In practice the field excitation may be reduced by adding resistance in the shunt field circuit, but can only be increased by using new shunt coils, or by increasing the e.m.f. impressed upon them. In most modern machines, which are built with the poles bolted to the frame, a considerable adjustment in the air-gap is possible. The poles are made short enough, so that by inserting sheet steel liners next to the frame, different air-gap lengths can be obtained in small steps over a considerable range. According to Fig. 2, one might think that the speed could be increased to the desired point by shunt resistance alone. The desired speed certainly could be obtained, but speed regulation would probably be bad, the machine more or less unstable, and the hot and cold speeds would vary greatly. It is true that certain adjustable speed motors will operate satisfactorily over wide ranges of speed. As high as 4 : 1 speed ratios are commonly obtained by shunt field control, but in the design of these motors special attention is given to the regulation at high speeds. A constant speed motor having practically a flat speed curve at its rated speed may have a decidedly rising

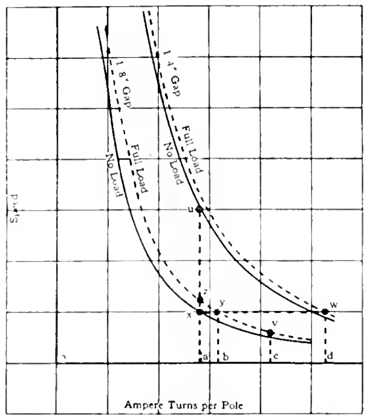

FIG. 2—TYPICAL SHUNT REGULATION CURVES

characteristic on weak field, thus it is hardly safe to depend on this method.

It is not always possible to distinguish a compound from a shunt motor by its series coils, for it is the practice of some manufacturers to supply series coils on the shunt machines also, except in the case of small sizes and high-voltage machines. The function of the series coil on a shunt motor is to insure stability and give a more nearly flat speed curve. In Fig. 2 *oa* represents the ampere turns supplied by the shunt coil. At no-load the speed will be *x*. If there is no series coil, the full-load speed will be equal to *z*. Plotting these values as speed curves, as in Fig. 3, it is found that the speed actually rises with the load. This is objectionable, and tends to produce an unstable condition. Now if a series coil be added which will supply *ab* ampere turns there is a total of *ob* ampere turns acting on the pole, which will give a speed at full-load equal to *y*, which is also equal to *x*; thus we have a flat speed curve *xy* in Fig. 3, which is desirable for a shunt motor. By using a series coil which will supply *ac*-ampere turns, a full-load speed equal to *v* is obtained. This gives a drooping characteristic, *xv* in Fig. 2, such as is desirable in a compound motor.

OPERATION AT VARIOUS SPEEDS

The explanation given above should be sufficient to enable one readily to know in which direction to change an air-gap. The points next to be considered are the range over which the speed may be changed, and the best way to go about its accomplishment. No definite rule can be given for determining the change in an air-gap necessary to give the required speed. It may be roughly stated that the percent change in the air-gap should be from three to four times the percent change in speed. This should be considered as only approximate, for accurate results can be calculated only with a full knowledge of the saturation curves. However, in most cases sufficiently accurate results can be obtained, unless the machine in question is worked high up on the saturation curve, where the iron is practically saturated, or very low on the curve, where the excitation is nearly all used in the air-gap. It is usually possible to change a speed from 10 to 15 percent by manipulation of the air-gap alone where the iron is not highly saturated. Of course, there are exceptions. In some cases no change at all is possible in the desired direction; in others a much greater change than stated can be obtained, all depending upon the length of air-gap in the machine. When a higher speed than can be obtained by increasing the gap alone is desired, it may be permissible to add such a resistance to the shunt circuit as will give the right speed. In this case the regulation should be checked carefully and possibly adjusted as explained below.

ADJUSTMENT OF REGULATION

For certain classes of work, such as a line shaft, practically constant speed is required from no-load to full-load. A shunt motor should be used to drive this type of load. Other classes require drooping speed characteristics, varying from the standard 20 percent regulation, to the heavily compounded bending roll motors, which have only enough shunt ampere turns to keep them from running away at no load.

Referring again to Fig. 2, it is obvious that if there are *oa* ampere turns at no-load, and *ob* ampere turns at full-load and a one-eighth inch air-gap, the speed curve will be flat, as *xy* in Fig. 3. Changing the air-gap to one-fourth inch gives a no-load speed equal to *u*. By adding series turns until the full-load ampere turns equal *od*, a speed *w* will be obtained, which is the same as that obtained at full-load with the smaller gap. This condition gives speed curve *uy* in Fig. 3, which is a compound characteristic.

From the above it is obvious that to obtain a compound characteristic from a shunt motor the air-gap should be increased, then series turns added until the full-load speed is the same as it was before. Flexible copper cable wound over the shunt coil, and tied in place, makes a very good series coil. It is easily wound, and requires no extra insulation. The copper section should be about the same as that of the old coils, so as to insure no overheating. When changing from a compound to a

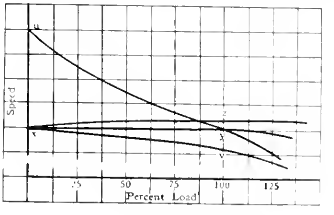

FIG. 3—TYPICAL SPEED CURVES

shunt characteristic a smaller gap should be used, and then current shunted out of the series coil until flat speed curves are obtained.

Considerable variations in speed curves can be obtained in this way, but again the saturation of the machine in question plays an important part in the range which is possible.

OPERATION AT OTHER VOLTAGES

Usually a motor is guaranteed to operate successfully on voltages ten percent over that for which it is rated. It has been shown that the speed varies directly as the impressed voltage and inversely as the flux; but the flux also changes with the voltage, although it is not a direct relation. The shunt ampere turns do vary directly with the voltage, but the flux does not follow the excitation on account of the saturation in the iron. It is obvious that if the flux should follow a direct relation, as in the case when operating on a weak field, where practically all the magnetizing force is required for the air-gap (see air-gap line in Fig. 1), the speed should remain practically constant over a considerable range. However, motors are usually operated well up on the curve for reasons of stability and economy, so this direct relation of exciting voltage to flux does not hold. In most cases the flux lags considerably, thus the speed will

follow the applied voltage more or less. When the voltage is not to exceed 20 to 25 percent over or under the rated value, it is usually possible to change the air-gap and obtain the correct speed. Great care should be exercised when operating at a considerable over-voltage to note the temperature of the shunt coil. This temperature will vary approximately as the square of the voltage, so it may not be possible to operate on full voltage without prohibitive heating. By making a full-load heat run one can determine the amount of resistance necessary to keep the temperature down to safe point. It is usually conceded that a coil will operate continuously with a 50 degree C. temperature rise without danger to the insulation. Taking this as an upper limit, most coils will be good for a considerable voltage increase, although much depends upon the liberality in the design of the coil in the first place. When a machine has the minimum air-gap, and the shunt coils are worked up to the maximum allowable temperature, nothing can be done to reduce the speed except to use new coils. In case of operating at a voltage lower than the rated, the maximum air-gap should be used and shunt field resistance inserted until the rated speed is obtained. In either case it may be necessary to adjust the series coil to obtain good regulation.

There are three common voltages used on direct-current circuits—115, 230 and 550 volts. The question may arise how to change a motor built for one voltage so as to operate on either one of the others. A 230 volt motor may have its shunt coils connected in two groups and paralleled, then connected across a 115 volt circuit. In this case the voltage per coil has not been changed, thus the flux will remain constant, but the speed will only be half what it was before. This can be brought up to the normal again by using the maximum air-gap and reducing the shunt field by resistance. When operating a 115 volt motor on a 230 volt circuit the minimum gap should be used and the shunt coil worked at the maximum temperature. This probably will not bring the speed down to the rated one, but it is the best that can be done without new coils. The same procedure follows when changing from one circuit to another. When going to a higher voltage use the minimum air-gap and shunt field resistance, but working the coils as hard as possible. When going to a lower voltage use the maximum gap and parallel the coils.

Armature Conditions—So far no change to the armature has been contemplated. It is evident that the current in the armature conductors should be left the same regardless of impressed voltage, so as to insure safe temperatures. An exception to this is at low speed where the ventilation is poorer, when the current may have to be slightly reduced. Since the horse-power output varies as the voltage, current and efficiency, it follows that for the same armature current the output will vary as the impressed voltage. This means that if a 115 volt motor be operated on a 230 volt circuit the horse-power will be doubled, although the speed has been kept nearly the same. The reverse is also true of a 230 volt motor on a 115 volt circuit.

SPEED REDUCTION BY MEANS OF RESISTANCE IN THE ARMATURE CIRCUIT

Equation (2) shows that the speed still depends on three terms:—$(E - IR_1)$, W_s and p. The number of poles cannot be changed, and W_s is a function of the armature winding and not very readily changed. The line voltage is also a constant. From the equation it is obvious that by increasing R_1 the speed at any load will be decreased, but that the no-load speed will remain the same. Since R_1 is internal resistance, or the resistance of the armature, commutating and series coils, it cannot be increased; but an external resistance R_2 can be connected in series, which has the same effect; thus the term becomes $E - I(R_1 + R_2)$. Since the speed varies as $E - IR$ or the counter e.m.f. the ratio can be obtained as in equation (3),—

$$\frac{Rm_1}{Rm_2} = \frac{E - I_1 R_1}{E - I_2 (R_1 + R_2)} \quad \ldots\ldots\ldots \quad (3)$$

$$\text{whence } R_2 = \frac{(Rm_1 - Rm_2) E + R_1 (I_1 Rm_2 - I_2 Rm_1)}{I_2 Rm_1} \quad (4)$$

Where Rm_1 = Present full-load speed.
Rm_2 = Desired full-load speed.
R_2 = Necessary resistance to be put in the armature circuit.
I_1 = Armature amperes at full load.
I_2 = Armature amperes at desired load.

Equation (4) gives an expression for determining the amount of external resistance, to be added to the armature circuit to give a desired speed reduction. Besides poor regulation, there is a considerable loss in the external resistance, which lowers the efficiency. In spite of these drawbacks it is often profitable to use this method of speed reduction where the load is practically constant and the low speed is only needed at intervals. The driving of blowers and centrifugal pumps comes under this head. With this class of service the power required decreases so fast with the reduction in speed that a comparatively small resistance is needed. About the only requirement for this external resistance is to be able to radiate the heat generated without excessive temperatures.

Using external armature resistance is merely a method of reducing the impressed voltage over the armature, by using up part of the line voltage in the resistance. Thus the mechanical horse-power output will be reduced in proportion to the reduction in armature voltage or to the reduction in speed, since they are proportional.

RECONNECTING THE ARMATURE

To get the best economy of material and the most efficient operation, the flux should be kept constant and the series conductors on the armature changed, so as to meet the various requirements [see equation (2)]. For example, take the question of operating a 115 volt motor on a 230 volt circuit. If the armature conductors be doubled and the copper section made half that used before, the speed and horse-power output will remain the same. The conductors will only carry half as much current as before, but the impressed voltage is doubled, so the watts input will remain constant.

Although changing the number of conductors on an armature is the ideal method, it is also the most difficult to accomplish. It is only in a few very special cases that an armature can be reconnected. Sometimes it is possible to obtain new coils from the manufacturer, but it is more often the case that the desired number of conductors can only be obtained with a different number of slots and commutator bars. With the use of commutating poles another complication enters.* For any change in a number of armature conductors there must be a corresponding change in the commutating pole coil. This usually means new coils. There are a number of other considerations that also enter, such as brush density, maximum voltage per commutator bar, etc. For instance, to maintain the same brush density in changing a machine from 230 to 115 volts, twice as many brushes must be used, which means twice as long a commutator; whereas changing from 115 to 230 volts with the same maximum voltage between bars requires twice as many commutator bars.† It is best to refer to the manufacturer when any change to the armature is contemplated.

OPERATION OF THE MOTOR AS A GENERATOR

It is usually a very easy matter to operate a generator as a motor, but when the attempt is made to operate a motor as a generator trouble is encountered in obtaining the required voltage at full load. This is not a fault of the machine, but is an inherent quality in the design. In the case of a generator the line e.m.f. is equal to the e.m.f. generated by the armature minus the resistance drop, while in a motor the line e.m.f. equals the armature e.m.f. plus the resistance drop. According to this, one would expect the terminal voltage at full load, of the motor operating as a generator, to be lower than the rated motor voltage by twice the resistance drop, assuming the speed, armature current and flux as remaining the same. The flux will not remain constant on account of the reduction of the voltage over the shunt coil, so that the terminal e.m.f. will fall still lower. In order to raise this voltage the first thing to do is to obtain the minimum air-gap; the speed at full load should then be noted running as a motor with the series coils cut out. The following equation will then determine the speed at which it will be necessary to operate, so as to obtain the desired voltage at full load, running as a shunt generator. It is well to increase this speed slightly so as to have some latitude for overloads.

$$R_{m_3} = R_{m_1} \frac{(E_3 + IR_1)}{(E_1 - IR_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where R_{m_3} = The speed when operating as a generator.
R_{m_1} = The speed when operating as a motor with the series field cut out.
E_3 = Terminal voltage at full load, operating as a generator.
E_1 = Line voltage as a motor.
I = Armature current.
R_1 = Internal resistance.

When operating as a compound generator the series coils should be adjusted so as to give the required compounding.

The changes as just considered apply to cases where the generator voltage is to be equal to or higher than the voltage as a motor. For instance, a 115 volt motor operating as a 125 volt generator, or a 230 volt motor as a 250 volt generator. Equation (5) is based on the assumption that the shunt excitation remains the same. This will only be true when a shunt field rheostat is used. Since it is not necessary that the shunt excitation be increased beyond what it was as a motor, the temperatures should not change. When it is wished to operate a 230 volt motor as a 125 volt generator it is usually sufficient to keep the same speed and air-gap, for the flux will not decrease as fast as the shunt excitation, on account of saturation. The output as a generator will be equal to the ampere rating as a motor multiplied by the voltage rating as a generator.

It may thus be taken as a general rule that for successful operation of a motor as a generator the speed must be increased. In certain cases this may not be necessary, for the decrease in the air-gap may compensate for the difference. This should be no very great drawback, however, for with belted machines the speed can be easily varied by use of different pulley ratios.

MECHANICAL LIMITATIONS

When increasing the speed of any motor or generator great care should be exercised not to allow the speed to exceed the limit of safe operation. It is not merely a question of the band wires or wedges withstanding the stresses due to centrifugal force, but also the rigidity of the coils. The insulation is more or less plastic, and when under stress the coils will shift slightly, which will throw the armature out of balance. An armature designed for high speed will not only have heavier banding, but the coils will be braced by coil supports. At high overspeeds it is also found that the commutator bars will deflect a certain amount. This distortion will reduce the brush contact and cause bad commutation. Usually the factor of safety is so large that a 25 percent increase in speed will be perfectly safe. Any greater increase should be taken up with the manufacturer.

CONCLUSION

From the foregoing discussion the question may arise: — Why are there no definite statements given which will govern direct-current machines in general? In answer to this it should be said that the characteristics of this type of machine depend largely upon the magnetic qualities. The magnetic defferences due to the various kinds of material, shapes of slots, poles, etc., as furnished by the different manufacturers make it impossible to lay down any simple relation which can be applied to all direct-current machines.

*See "Theory of Commutation and Its Application to Interpole Machines," by Mr. B. G. Lamme, in the *Proceedings of the A.I.E.E.* for October, 1911.

†See "Flashing in Direct-Current Machines," by Mr. B. G. Lamme, in the JOURNAL for March, 1916, p. 145.

Notes on the New Code of Lighting for Factories, Mills and Other Work Places*

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A NUMBER of influences have been effective during the past few years in helping to bring about improvements in factory lighting. Perhaps the most important are the following:—

a—The development of new lamps better suited than older types to the conditions imposed in factory lighting.

b—The interest of factory owners and executives in the economic returns promoted by good lighting.

c—The effect of public opinion, as indicated by the technical and popular press, in directing attention to the importance of improved factory environment.

d—The effect of compensation laws in stimulating efforts to improve accident prevention methods.

e—Municipal and state legislation tending to place industrial lighting on at least a minimum standard basis.

Although the attention to factory lighting on the part of executives and managers, as well as individual engineers, has been quite marked recently, there is much room for improvement in the matter of standards of illumination intensity for various factory operations, and in many quarters there is still great ignorance of the most elementary features of illumination and their relation to factory production. As late as December, 1913, in a letter to the writer, Dr. A. Blondel, a member of the Academy of Sciences of Paris, in commenting on a contribution to *Science et Art de l'Eclairage*, made the following statement:—

"I am sure that the readers will accept the article with very great interest, for in France we are as yet very little advanced in the subject on which you have written, at least from the standpoint of exact rules. Moreover, the propositions† you develop on the subject of the resulting economy of good lighting are but very little known in France."

About two years ago, in England, a departmental committee on lighting in factories and workshops was appointed by Hon. Reginald McKenna, Home Secretary of Parliament, for the purpose of investigating actual factory lighting conditions in Great Britain, on a basis of which recommendations might be made covering industrial lighting. The first report of this committee was made public in the fall of 1915. A statement found in the preliminaries of the British report furnishes an excellent idea of the spirit back of the recommendations of that committee. It follows:—

"On the other hand, it must be admitted that many employers have lagged behind in the general advance. This applies especially to old factories, designed before the importance of illumination was generally recognized, and to small workshops, of which the occupiers perhaps hesitate to expend the capital necessary for improvement.

"It is obvious that any requirements which would tend to bring such places up to the level of the more progressive firms would be beneficial, not only to the operative by improving his working conditions, but also to the employer himself by increasing his output. Light is a cheap commodity, and little or no hardship should result from such requirement, if gradually and sympathetically enforced."

EFFORTS OF THE ILLUMINATING ENGINEERING SOCIETY

The Illuminating Engineering Society of this country‡ has felt for some time a growing need for an authoritative code of factory lighting, which could be used by factory managers for improving the lighting conditions in their own plants or which, to equal advantage, could be employed as a basis for lighting legislation. For a number of years the society has had a committee known as the committee on lighting legislation, which has done considerable work; but the need for a working guide led to the appointment early in 1915 of a new committee, known as the committee on factory lighting, which was assigned the work of drafting out such a code of lighting. Preliminary to the work of drafting this code a careful study was made of existing lighting legislation. Among the most important efforts in this line thus far have been the shop lighting orders of the state of Wisconsin and the legal enactments of New York state. Digests of all legislation related in any way to lamps or lighting were obtained from a number of states, all of which pointed conclusively to the fact that nothing of any practical value is to be found in a majority of the state laws in this country concerning the regulation of industrial lighting.

ATTITUDE OF THOSE RESPONSIBLE FOR THE CODE

In preparing this working guide great care was exercised to make clear to factory owners the real underlying advantages of good lighting, which are not based on legislation, but which should appeal to any progressive factory operator from the standpoint of efficient production methods. Perhaps no better idea of the attitude of those who drafted the code can be given

*This code was prepared jointly by the committee on factory lighting and the committee on lighting legislation of the Illuminating Engineering Society, and was presented for the first time at the last annual convention of the society. The code has been accepted by the council and is issued in separate pamphlet form by the society, 29 West Thirty-ninth street, New York, N. Y.

†Propositions of this general nature were developed as early as May, 1910, in this country, one of the first references being found in an editorial by Mr. Charles F. Scott in the Journal for May, 1910, p. 333.

‡The Illuminating Engineering Society of America was formed in 1906. A society of the same name was organized in London in 1909.

than is found in the brief preface to the document. This is quoted because there is always a considerable chance for misunderstanding when new regulations are suggested covering any of the various branches of industrial organization:—

"The following code of lighting for factories, mills and other work places has been prepared by committees of the Illuminating Society in order to make available authoritative information for legislative bodies, factory boards, public service commissions and others who are interested in enactments, rules and regulations for better lighting. While the code is intended as an aid to industrial commissions and other similar bodies in those states and municipalities which shall actively take up the questions of legislation as related to factory and mill lighting, it is intended in equal measure for the industries themselves as a practical working guide in individual efforts to improve lighting conditions. The language of the code has not been drafted according to legal phraseology, but is simple and pointed throughout, thus being readily available for transforming into legal orders, and at the same time as a working guide in practical design and installation work."

Several paragraphs from the report of Mr. L. B. Marks, chairman of the committee on lighting legislation, placed before the last annual convention of the Illuminating Engineering Society also have a bearing on this code. They are as follows:—

"During the early part of the past year (1915) the committee on lighting legislation made a general survey of the state laws relating to lighting in the United States and prepared a transcript (taken from the statute books) of the laws relating to lighting in the states of New York, Pennsylvania, Connecticut, Illinois and Wisconsin. The study of these laws led to the conclusion that, with few exceptions, existing state lighting legislation is crude, fragmentary and often meaningless.

"It was suggested that this committee frame a model lighting law to serve as a guide to legislators contemplating the enactment or amendment of laws pertaining to lighting. The difficulties in the way of framing a model law applicable to all classes of lighting are apparent and the committee decided to confine its work for the present to formulating a code of lighting for factories, mills and other work places and a code of lighting for schoolhouses.

"Accordingly, a special committee on factory lighting and a special committee on school lighting submitted to the committee on lighting legislation, technical data and rules upon which to base a lighting code. A large part of the attention of the committee on lighting legislation has been devoted for the past six months to the consideration of a comprehensive report of the factory lighting committee, of which Prof. C. E. Clewell is chairman, containing material upon which was based the code of lighting now placed before you.."

CONTENTS OF THE CODE

The entire document, consisting of 45 pages, is divided into three parts. One of these defines in eleven brief articles the recommendations for legal enactment; a second part sets forth a number of simple rules as an aid to successful lighting; and a third part consists of an extended discussion of the fundamental principles of illumination as applied to factory conditions, under the heading "Explanatory Notes." The third part of the code has been considered a necessary adjunct to the legislative articles, because articles of this kind are often difficult to interpret unless sufficient explanatory material is added for the benefit of those who perhaps approach the subject for the first time.

As a basis for the brief analysis of the code articles to follow, the eleven suggested legislative articles, together with the "Explanatory Rules," are presented:—

Article I—Daylight—All buildings hereafter constructed must be provided with adequate window area. Awnings, window shades, diffusive or refractive glasses must be used for the purpose of improving daylight conditions or for the avoidance of excessive brilliancy wherever they are essential to these ends.

The windows, skylights, saw-tooth or other roof lighting constructions are to be arranged with reasonably uniform bays, and the daylight openings shall be so designed and proportioned that at the darkest part of any work space, when normal exterior daylight conditions obtain, there shall be available at least a minimum intensity equal to three times the minimum intensities given in Article V for artificial light.

The intensity requirements for daylight are higher than those for artificial light because the physical condition of the eye during the daytime is usually such as to require a higher intensity of natural light for satisfactory vision than is required at night under ordinary well-designed artificial lighting systems.

Article II—Old buildings at present constructed and not having adequate window area must be provided with adequate artificial light according to the following articles, so as to supplement the natural light during normal daylight hours.

Article III—All buildings, whether old or hereafter constructed, must be provided during those hours of work when natural light is insufficient or not available with adequate artificial light according to the following articles:—

Article IV—Adequate intensity of the light must be provided for each class of work, both on a horizontal plane as well as on a vertical plane passing through the work, according to Article V. In all cases, however, glare on working surfaces is to be avoided, as it tends to reduce the visual efficiency of the workmen and to increase the likelihood of accidents.

Article V—Artificial Light—Intensity Required—The average illumination intensity throughout any month actually measurable in foot-candles on a horizontal plane through the work is to conform to the following table. Uncertain cases which arise as to how to classify given manufacturing operations are to be left to the judgment of a lighting expert.

Class of Work	Minimum foot-candle intensity	Desirable foot-candle intensity
Storage, passageways, stairways, and the like	0.25	0.25–0.5
Rough manufacturing and other operations	1.25	1.25–2.5
Fine manufacturing and other operations	3.50	3.5–6.0
Special cases of fine work	——	10.0–15.0

Where operations are performed on the sides of the work in hand they shall be classified according to this table, and if the illumination is furnished from an overhead system it shall preferably *be not less than 50 percent* of the foregoing values when measured on a vertical surface. If the illumination is furnished by an individual lamp or by lamps close to the work the intensity shall conform to the minimum or desirable intensities required in the foregoing table.

As a guide to inspectors and others, it may be stated that with modern lamps roughly one candle-power per square foot produces an effective illumination of three foot-candles when the lamps are arranged according to the uniformly distributed overhead system, with mounting heights ranging from 12 to 16 feet above the floor, and when the light is directed from said lamps to the work in an efficient manner. A rough idea may thus be secured of the candle-power per square foot necessary to conform to the foregoing table of intensities by taking *one-third of the intensity values given in the foregoing table.*

Thus, for fine manufacturing and other operations, the minimum foot-candle intensity is 3.5, which is approximately equal to 1.2 candle-power per square foot. The use of a portable photometer or illuminometer, however, is recommended for the determination of existing systems, and all uncertain cases are finally to be established by these instruments.

Article VI—Lamps and machinery jointly are to be so arranged as to avoid the casting of shadows over belts and other obstructions on important parts of the work, and the distribution of light from the lamps should be such as to avoid sharp contrasts of light and shade on the work.

Article VII—Inspection and regular maintenance of all lighting systems is required in spaces where work is being conducted, and in no case must the lighting devices, whether windows, lamps or auxiliaries, such as globes and reflectors, be allowed to deteriorate, due either to dirt accumulations or to burned-out lamps, more than 20 percent below the minimum intensity values required by Article V.

Article VIII—Roadways, yards and places not usually frequented must either be provided by illumination during working hours when natural light is absent or partly absent, to make them safe against accident to employees traversing or engaged in such places, or a convenient control or controls must be placed at the entrance to basements, stock rooms, and the like, so that a person on entering can readily turn on the lamps beforehand.

Article IX—Stairways and passageways must be provided with lamps and reflectors or shades carefully located so as to shed their light generally over the entire space or spaces involved, and in sufficient quantity to make the stairways and passages safe against accident to employees traversing or engaged in such places. For intensities see Article V.

TABLE I—COMPARATIVE INTENSITIES

CLASS OF SERVICE	Handbook on Incandescent Lamp Illumination, G. E. Co.	Clewell's "Factory Lighting"	Handbook on Shop Lighting, Wisconsin Industrial Commission*	I. E. S. American Code	British Report
General illumination for work rooms, independent of the actual light required for the work.	0.8	...	....	...	0.25
Foundries	3.0	...	1.5	....	0.4
Passages	...	...	0.08	0.25	0.1
Yards	0.1	...	...	...	0.05
Rough manufacturing	2.0	3.0	0.75	1.25	
Fine manufacturing	5.0	5.0	1.5	3.5	....
Storage	0.5	0.5	...	0.25	...

*The quantity of light specified in the Wisconsin orders is in terms of candle-power per square foot ten feet above the floor. The intensity values in this column have been calculated on the basis of tungsten lamps with an efficiency of one watt per candle, mounted overhead with efficient reflectors. This furnishes an approximate comparison with the other intensities listed.

Article X—Each working space is preferably to be illuminated by lamps mounted overhead, according to the system of general lighting, in preference to individual lighting. The overhead method of lighting, besides possessing many other advantages, also tends to reduce dark spots throughout the floor area, a feature usually objectionable with the use of individual lamps. This particular article is not an absolute requirement, but a suggestion enforceable at the discretion of a lighting expert.

Article XI—Auxiliary lighting should be provided in all large work spaces, such lamps to be in operation simultaneously with the regular lighting system, so as to be available in case the latter should become temporarily deranged.

EXPLANATORY RULES

The foregoing eleven articles are intended as the basis for legislation and also to furnish a practical working guide for the design and installation of factory systems. As a further aid in the observance of the articles, appended rules present the more important features of such work from a slightly different angle, and hence form a useful supplement to the articles proper. These eight rules take the following form:—

1—Lamps should be equipped with reflectors or shades for minimizing glare and economizing light. Bare lamps should not be used except in rare cases, and then only when out of the line of vision.

2—As a general plan, mount the lamps high and out of the ordinary line of vision.

3—Although the types of reflectors and shades, and reflector and shade holders or fitters on the market are numerous, it is recommended that the holder or fitter, as well as the reflector or shade be selected with reference to placing the light source at the proper point in the reflector or shade so as to eliminate glare, due to exposure of the light source, and also for the purpose of directing the light from the lamp effectively to the work, that is, for obtaining a distribution of light which meets the desired requirements.

4—Light thrown vertically downward is not the only important component of the resulting illumination. The sides of machinery, machine tools and work, as well as horizontal surfaces, often require good light.

5—Control few lamps in each group, so that lamps not needed may be turned off conveniently.

6—Keep windows, lamps and reflectors clean, since large losses of light result from the accumulations of dust and dirt.

7—Provide a maintenance department if the shop is large enough to warrant it, so that all the items associated with the upkeep of the lighting system may be cared for systematically.

8—Keep ceilings and upper portions of walls a light color for the purpose of rendering both natural and artificial lighting more efficient and better diffused. The lower portions of walls should be a color which is restful to the eyes, preferably a medium tint, typified by the tint known as *factory green*, or a rather dark shade of yellow. Other medium tones are also available.

EXPLANATORY NOTES

Following these articles and the rules, the code contains seventeen sections under the general title "Explanatory Notes," which apply in amplified form to the items in the articles and rules. These Explanatory Notes are treated under the subheads of daylight; value of adequate illumination; old and new lamps; effects on factory and mill lighting produced by modern lamps; general requirements of artificial lighting; overhead and specific methods of artificial lighting; various locations illustrated; lighting circuits for electric lamps and supply mains for gas lamps; control of lamps and arrangements of switches; systematic procedure should be followed in changing a poor system to an improved arrangement; reflectors and their effect on efficiency; side light important in some factory and mill operations; maintenance; expert assistance suggested; other features of eye protection; auxiliary systems for safety; and good and bad lighting compared.

CODE REQUIREMENTS MODERATE

The fact that many industrial concerns throughout this country located in states not having lighting legislation are illuminated to standards considerably higher than those called for in the legal regulation of other states where such laws are in force, and also higher than those specified by this new code, are indications that there is much to be hoped for and expected from influences other than legal requirements among all the influences which are helping to improve existing lighting conditions. At the same time, many instances are apt to persist either through ignorance or willful neglect where illumination is below the minimum standard set by this code, and it is for cases of this kind that legislation is particularly necessary.

As an example of the comparative values of illumination recommended for representative classes of work in the code and by other authorities, Table I has been

compiled to show similar intensities suggested in this country and in England by the terms of the new report of the departmental committee on the lighting of factories and mills. In this table it should be noted that the values recomended by the American and British codes are minimum values, while some of the other values must rather be interpreted as mean values based on general practice.

The five headings for the vertical columns of Table I indicate the source from which the intensity values are taken. The Handbook on Incandescent Lamp Illumination issued by the General Electric Company and the book on "Factory Lighting," by Mr. C. E. Clewell, were each published in 1913; the Handbook on Shop Lighting issued by the Wisconsin Industrial Commission appeared in 1914; and the American code and British report were each made public in 1915. The first two columns may be taken as typical of good practice in factories which have gone ahead with the lighting problem for the purpose of realizing the best conditions for production, while columns three, four and five represent the most prominent cases of lighting legislation thus far.

FIG. 1—FACTORY SPACE ILLUMINATED BY TUNGSTEN LAMPS AND METAL REFLECTORS

The space appears gloomy. Compare with Fig. 2.

The numerical values in the various columns refer to the intensities of illumination in foot-candles on the working surfaces to be lighted. This table shows the interesting fact that practically all attempts at legislation up to date have resulted in recommended intensities considerably lower than the average practice in good lighting installations. The legislative values are therefore conservative. In Article V of the Illuminating Engineering Society's code, the intensities recommended are placed in two columns, one being a *minimum* and the other a *desirable* column. Many factories in following out the suggestions of the code will doubtless be guided by the desirable rather than the minimum values, because of the added advantages which follow a liberal policy in the matter of lighting.

BRIEF ANALYSIS OF THE CODE

A review of the code shows that it includes natural as well as artificial lighting, and that the subject of artificial lighting is treated for both gas and electric supply. The features of natural lighting, which are not explained fully in the articles, are treated at considerable length in the "Explanatory Notes," which form part three of the code.

One of the most interesting, and it is believed important features of this new guide book, is the method of specifying quantity of light. Article V shows that the intensities are stated in terms of the foot-candle intensity on the working surface. In the case of one state, the law specifies so many candle-power per square foot mounted ten feet above the floor. This plan has the disadvantage that no specification is made regarding the actual quantity of light on the work. If, for example, a 100 candle-power lamp is mounted ten feet above the floor for every 100 square foot of floor space, we then have one candle-power per square foot. If the lamp is fitted with an efficient reflector the illumination may be sufficient; if, however, no reflector is used, the illumination on the work may be far from satisfactory. In either case we should have one candle-power per square foot.

By referring all intensities to the working surface, a specification is realized which may be checked up through the medium of portable photometers or illuminometers, for uncertain cases, or for the purpose of

FIG. 2—THE SAME FACTORY SPACE AS THAT SHOWN IN FIG. 1.

The use of glass reflectors changes it from a gloomy to a bright and cheerful interior.

helping a factory owner to ascertain whether or not he is complying with good practice.

OTHER ITEMS

Throughout the code considerations of safety are emphasized. Much importance is attached to the proper lighting of roadways, yards, stairways, passages and, in general, such places which are not often frequented, as an aid to accident prevention. Records of industrial accidents indicate conclusively that neglect of these out-of-the-way places is the cause of much unnecessary accident trouble. Reference is also made to auxiliary lighting. In all work places where a large number of people are engaged, at such periods where artificial lighting is depended upon, there should be an entirely separate source of illumination in case the main source fails due to some failure in the supply system. The example of the Bureau of Water Supply, Gas and Electricity in New York City is cited, where all buildings coming under its jurisdiction are made the subject of a ruling of this kind.

Emphasis is placed on light interiors as an aid to more efficient intensities of illumination from a given installation of lamps, and for the purpose of improving the diffusion and increasing the amount of illumination furnished to the sides of work from overhead lamps. In the comparison between glass and metal reflectors for incandescent lamps, the added cheerfulness of glass reflectors is explained. It is not generally understood that glass reflectors can be used to very good advantage in factory service, and that besides making a section appear brighter and more cheerful, the resulting illumination can be as great with the glass as with the metal equipment. Figs. 1 and 2 illustrate this feature, the two views showing the identical floor area in which lamps of the same size are equipped, first, with metal reflectors, and second, with glass reflectors. The very much improved appearance of the place with glass reflectors is shown by these views.

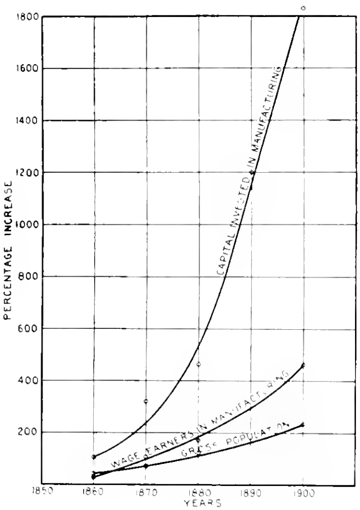

FIG. 3—CURVES SHOWING THE PERCENTAGE INCREASE OF POPULATION, WAGE-EARNERS AND CAPITAL INVESTED IN MANUFACTURING IN THIS COUNTRY FOR FIFTY YEARS

CHANGES IN THE INDUSTRIES

In studying a table like the one just discussed, and finding that very little progress has been made up to the past year or so towards standardizing industrial lighting, the question naturally arises as to why there has been such a delay in the appreciation of the part played by good lighting in factory buildings. The answer may lie in the fact that the industrial growth in this country has been very rapid, and the demand for greater output from existing plants may have resulted in the past in a certain apathy on the part of factory owners to everything that did not seem to bear directly on the efficiency of production. The percentage increase in the total population of the country is compared in Fig. 3 with the percentage increases in wage-earners and in capital invested in manufacturing for the corresponding years.

The very much more rapid increase in wage-earners and in capital than the growth of population indicates in a way, at least, that the past years have imposed on the manufacturing interests in this country a problem of such magnitude that it is reasonable to conclude that everything, or at least most things, have been overlooked which could not be charged with some responsibility in helping to increase the output of the plants. Those items of comfort, convenience and indirect aids to working efficiency have rather come to the front during very recent years.

Quite recently many new influences have been felt. Welfare departments, safety first organizations, efficiency movements and the like have approached manufacturing methods from a new point of view, and lighting has been one of the features to receive very marked attention through some of these other channels.

PROBABLE USEFULNESS OF THE CODE

The new code appears at a time when a new interest is being taken in lighting, not so much for its technical aspects, as for the part it plays in the economy of production. Its widespread reception by practical factory men has proved that there is a demand for such a working guide, even in the few months since its appearance. When these same regulations are placed into legal requirements, an additional factor, that of the ways and means for sympathetically and gradually enforcing these rules, will require attention. The industrial commission or the labor department must first show the poorly lighted factory why better lighting is an advantage; then the methods to be followed should be available if the factory is to conform with the legal enactment. In factory lighting work it is doubtful if a code even as complete as this can be depended upon to indicate methods of design and installation for well-planned lighting systems, and in many cases there may be a necessity for a factory to call in outside expert assistance to help in solving some of the troublesome problems involved.

Much of the success to be obtained where legislation must be enforced will doubtless depend on the spirit back of the department on which the responsibility for this enforcement rests. If the factory owner is encouraged to study illumination in its economic aspects, that is, as an aid to the production rate in his plant, much more is apt to be gained than if the attitude is taken that an arbitrary law is to be enforced and must be complied with irrespective of its bearing on the routine of the plant in question. Any labor department can thus take an attitude, at least as regards factory lighting, of such a nature that practically all factories, when a full realization is secured of the advantages of good light, will be led to comply with reasonable legal requirements, and in this manner the problem of enforcing the law will rather take on the form of a co-operative effort to bring about a much-delayed improvement.

The Engineering Evolution of Electrical Apparatus—XXI

THE HISTORY OF THE LIGHTNING ARRESTER

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IN THE old days when the Westinghouse Electric Company was down in Garrison alley, Paul Windsor suggested that a lightning arrester arc rupturing device might be made by placing the spark gap in the neck of a bottle so that the expanding air in the bottle would blow out the arc. While this was a good deal like "pulling yourself up by your boot straps" it, nevertheless, gave a suggestion which led to the construction of the first automatic lightning arrester manufactured by the Westinghouse Electric Company, the only other lightning arresters in use at that time being the old "saw-tooth" with a fuse and the Thompson magnetic blowout. Instead of placing the spark gap in the neck, it was placed down in the body of the bottle and in the neck there was placed a circuit interrupting device which consisted of a gap made of carbon terminals and bridged with a carbon ball, the carbon ball being confined in a metal tube provided with vent holes and a soft rubber bumper at the top, Fig. 1. In the double-pole lightning arrester shown there are two air chambers, with a spark gap in each, and two circuit interrupting devices, one for each air chamber.

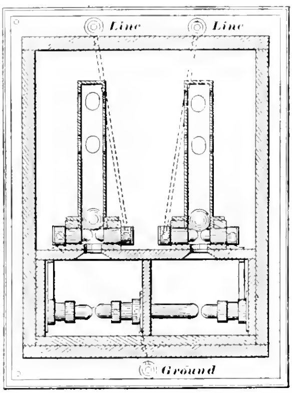


FIG. 1—DOUBLE-POLE LIGHTNING ARRESTER

This type of lightning arrester was designed for use on 1000 volt alternating-current circuits, and in testing it for this service the spark gaps in the air chambers were bridged with crumbs of tin foil. The binding posts were connected to either side of the circuit, and on closing the switch a short-circuit was established, fusing the tin foil and establishing a considerable arc between the terminals of the spark gaps in the air chambers, the heat of which in turn expanded the air, blowing it violently out through the vents, carrying with it the carbon balls, and thereby establishing arcs between the carbon terminals of the circuit interrupting device, which were instantly extinguished by the rush of air.

This type of lightning arrester was designed and placed in service about 1890 and was successfully and extensively used until it was replaced with other and more simple devices. It was not adapted for use on either arc or 500 volt direct-current circuits. The principle of blowing out the arc was, however, again brought into service in designing suitable lightning arresters for these circuits.

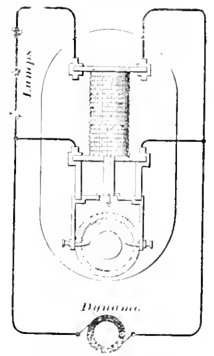


FIG. 2—LIGHTNING ARRESTER FOR SERIES ARC CIRCUITS

The construction of the arc circuit lightning arrester with its connections is illustrated diagramatically in Fig. 2. In the lower part of the figure a carbon ball is shown fastened in the center of an air chamber and two spark gaps, constituting the two gaps of a double-pole lightning arrester, which are formed by metal arms pivoted above and swinging into the air chamber through suitable openings and forming spark gaps with the carbon ball. It was found, however, that a short-circuit from a constant-current arc machine did not develop enough heat to expand the air and blow the terminals out through the openings. This difficulty was overcome by connecting a solenoid and plunger core in the main circuit so that under normal conditions the plunger would be held up. If, however, a lightning discharge should occur, causing a short-circuit through the lightning arrester, the core would drop on the lever arms, thereby forcing the curved terminals out of the air chamber, which in turn would draw out a considerable arc between each terminal and the carbon ball and thereby expand the air and blow out the arc, thus interrupting the short-circuit. The core would then be drawn up again to its normal position ready for further action. This lightning arrester was also extensively used by the Westinghouse Company as their standard arc circuit lightning arrester.

Neither of the two types of lightning arresters already described were adapted in their circuit interrupt-

ing properties for use on 500 volt direct-current circuits. In the design of a lightning arrester for this service the same principle of air expansion was adhered to and, after some experimenting, the form shown in Fig. 3 was designed. This was called the "pick-axe" lightning arrester. A reciprocating arm holding a curved carbon

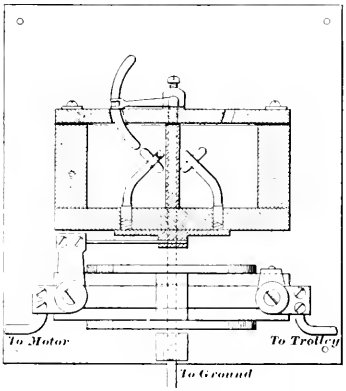


FIG. 3—PICK-AXE LIGHTNING ARRESTER

was fastened at the center between two air chambers, the carbon forming a spark gap with grounded terminals in either of the air chambers. The action of this lightning arrester was as follows:—

On the passage of a disruptive discharge the current would follow, causing a short-circuit as in the other types of arresters, and thereby developing heat sufficient to expand the air in the air chamber and blow the pick-axe terminal from one chamber over into the other, at the same time blowing out the arc. To avoid breakage of the curved carbon it was reinforced with a metal tube, leaving only the carbon tips exposed. While this form of lightning arrester operated satisfactorily as far as the interruption of the short-circuit was concerned it had drawbacks. For instance, it required rather nice adjustment, so that the swinging arm would not touch and perhaps stick in the vents; then sometimes the arm would be thrown out so violently as to cause it to rebound from the second chamber back into the first. It also did not lend itself readily to double-pole construction. This form was subsequently modified to a form shown in experimental operation in Fig. 4.

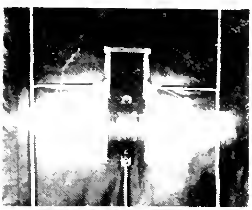


FIG. 4—MODIFIED FORM OF PICK-AXE ARRESTER

The arrester is shown in the act of interrupting a short-circuit on a 500 volt street railway circuit.

The air chamber in this case is a metal cylinder, the ends of which are closed with flat pieces of marble. Carbon swinging arms were provided which penetrated the marble walls and, when hanging normally, formed spark gaps with a fixed carbon ball in the center of the air chamber, as shown in the arc circuit lightning arrester, thus forming a double-pole lightning arrester. For single-pole service the inner carbon ball was omitted and the swinging arms were allowed to form a spark gap between their own tips. Above the air chamber there is a device which looks like a handle, but which in reality constitutes two bumpers, one for each of the swinging arms. In action the arms were blown out with great violence and the heated vapors expelled through the vents in the marble walls.

This form of lightning arrester, however, soon developed a serious defect. The swinging arms being suspended in a vertical position proved to be sensitive to the jarring motions of street cars, and were constantly swinging in and out, thereby momentarily placing the lightning arrester out of service. To avoid this difficulty it was suggested that the marble covers be inclined at an angle, as shown in Fig. 5. With this construction gravity tended to keep the swinging arms in a normal position, thereby avoiding the swinging action which was found so objectionable in the former type. This lightning arrester, from its shape, was called the "Keystone lightning arrester," and for a number of years was manufactured by the Westinghouse Company as their standard railway lightning arrester for both street car and station service. The station arrester was mounted on a marble base, as shown in Fig. 5, and the street car, or outdoor type, was mounted in an iron box lined with asbestos, as shown in Fig. 6.

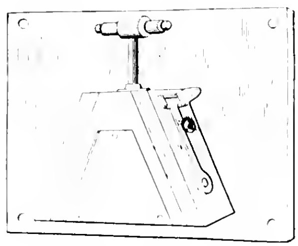


FIG. 5—KEYSTONE LIGHTNING ARRESTER
For switchboard mounting

The lightning arresters thus far described depended for their action on a short-circuit and they had moving parts. Both of these features were objectionable. In the case of the railway lightning arrester the short-circuit required a good ground connection and this was not always obtained, perhaps not always obtainable. The writer remembers one instance where the Keystone lightning arrester was grounded to a copper plate of ample dimensions buried in clay. The complaint was made that, while the lightning discharge would pass, the arrester failed to interrupt the short-circuit. On investigation this was found to be true, but the resistance of the ground connection was so high that not more than five or ten amperes could pass. The explosive action could not take place and the "short-circuit" arc was not interrupted. On changing the ground connection to the ground bus and then using tin foil to start the arc, as already described, it was demonstrated to the satisfaction of the attendant that the fault lay, not with the lightning arrester, but with the ground connection.

Barring an occasional instance of this kind the short-circuiting through the lightning arrester did not prove a serious matter. The moving parts did, however, on occasions lead to trouble. In shipping it was found desirable to tie the arms in place, and this was most conveniently done by using a rubber band. On reaching their destination the lightning arresters were frequently installed without removing the rubber bands, contrary

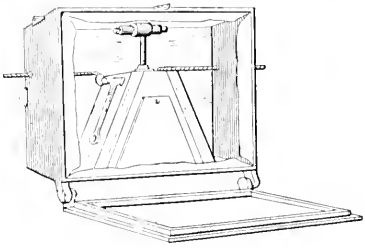


FIG. 6—KEYSTONE LIGHTNING ARRESTER
Outdoor type.

to the printed instructions sent with each instrument. In fact, in many cases it was found that the rubber bands were thought to be a necessary part of the lightning arrester, and for that reason were not disturbed. It is needless to add that in such cases these lightning arresters failed to give satisfaction. In other words, they were not fool-proof.

About this time, 1892, it was the general practice to depend for protection upon a single lightning arrester connected to each circuit in the station and, while a few outdoor lightning arresters were used, there was no general attempt made to provide frequent paths to earth for lightning discharge and, as numerous complaints were made of damaged apparatus due to the failure of the lightning arrester to carry off the discharge, it became more and more evident that for effective protection lightning arresters should be used in greater numbers along the line. Owing, however, to the expense, not only of the lightning arrester, but of the installation, it seemed hopeless to expect the adoption of any such plan, for the lightning arrester was looked upon by station managers as a strictly non-dividend paying device.

Looking now toward a cheaper, smaller and more simple lightning arrester than those already described, and particularly to the elimination of moving parts, the idea was conceived of placing simple spark gaps out on the line and providing a circuit breaker in the station which, upon the short-circuiting of any of these spark gaps, would open and immediately close again automatically. This was, of course, not ideal, but, nevertheless, it placed all the moving parts of the lightning arrester system in the power house, where they could be watched and could receive attention; and it did not seem quite so bad to interrupt the service for an occasional second or two, in view of the practice in many places in those days of opening the station switches until the storm had passed.

In experimenting with this system carbon spark gaps were used and, as already described, the short-circuit was established by crumbs of tin foil. The first experiment produced the following result;—when the short-circuit was established the circuit breaker opened and immediately closed again as was intended, but so quickly did this operation take place that the short-circuit was immediately re-established through the white hot carbon terminals of the spark gap. Again, the circuit breaker would open and close with the same result, and for the same reason. This indicated that carbon was not a suitable material for spark gaps to be used in this manner.

Thinking that metal terminals might be used to better advantage, and that by using them the re-establishing of the short-circuit would be avoided, spark gaps were made with terminals of brass rod about 1.5 inches long and one inch in diameter and with a 1/32 inch air space between the two terminals. On short-circuiting with crumbs of tin foil, as before, it was noticed that, although the circuit breaker did not open, still the arc in the spark gap was interrupted. This was a very remarkable performance, and the reason for it was by no means evident. It should be observed here that these experiments were performed on a small 1000 volt alternator, having a smooth body armature, such as were commonly made at that time.

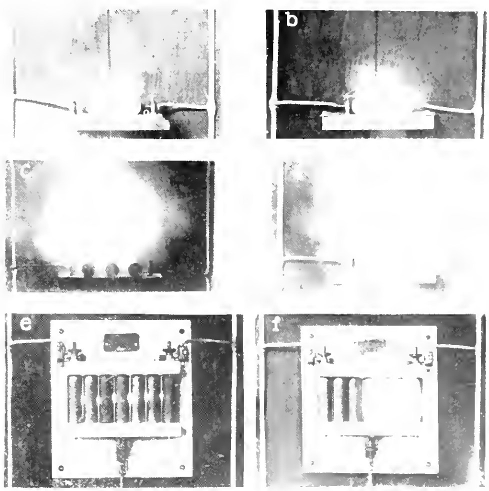


FIG. 7—TESTS ON NON-ARCING CYLINDERS

a—The interruption of a short-circuit between non-arcing metal electrodes with two 1/32 inch air-gaps

b—The interruption of a short-circuit between non-arcing metal electrodes with two 1/16 inch spark gaps

c—A short-circuit maintained between non-arcing metal electrodes with two 5/8 inch air-gaps; otherwise the same conditions as above.

d—Maintenance of short-circuits between copper electrodes with 1/16 inch spark gaps.

e—Interruption of short-circuit with six 1/32 inch spark gaps between non-arcing metal electrodes.

f—Interruption of short-circuit with three 1/32 inch spark gaps.

All the tests were made on the same machine and under the same conditions.

This experiment was repeated several times, and each time with the same result. Thinking that something must be wrong, and not knowing what it could be, the gaps with the carbon terminals were again placed in series, but these acted as formerly, producing the expected short-circuit and opening and closing of the circuit breaker. It now seemed evident that the cause for the interruption of the short-circuit when using the brass terminals must be looked for in the nature of the terminals, although the reason was not at all clear. One thing was certain, there was a very great difference between the action of brass terminals and carbon terminals. Thinking that possibly the speed and voltage of the small alternator which was being used might be considerably reduced by the short-circuit and that this might be a factor in the interruption of the short-circuit when using brass electrodes, it was decided to perform the same experiment on a much larger machine. At the moment this was not available. So, in preparing for this test, thinking that possibly larger terminals might prove more effective, three cylinders were ordered, each about three inches long by three inches in diameter. These were fastened to a board with spark gaps of 1/32 inch between adjacent cylinders, thus giving two spark gaps in series. The two end cylinders were connected to binding posts. As soon as one of the large 1000 volt alternators was available (it was the largest one constructed at that time and was called a "3000 lighter") this device, consisting of the three large cylinders with the two spark gaps, was laid on the floor and connected to the terminals of the alternator with an open switch in series. The field switch was also at hand. Crumbs of tin foil were dropped into the spark gaps and the short-circuiting switch closed. In an instant there was a groan from the dynamo, a great squeaking of the belt and the massive cylinders were instantly melted to an almost shapeless mass. This was discouraging, to say the least, but thinking that there still might be some virtue in the smaller brass terminals that had been used in the previous tests, these were connected up in short-circuit in the manner already described. The short-circuit was instantly interrupted with the formation of an arc no larger than was occasioned by the melting of the crumbs of tin foil and the brass cylinders were undamaged and showed no tendency to fuse together. This test was then repeated many times, proving conclusively that there was some virtue in the small brass cylinders which did not exist in the large cylinders and that a short-circuit on the 1000 volt, 3000 light alternator could be interrupted instantly by two 1/32 inch spark gaps after the short-circuit had been established without any demonstration on the part of the generator and without injury to the brass terminals. While the mystery was still deep it was evident that an important discovery had been made. Not only this, the whole performance was unthinkable, so contrary was this action to the commonly accepted ideas at that time regarding the behavior of metals under these conditions.

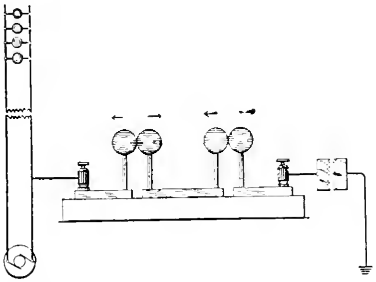


FIG. 8—NON-ARCING CYLINDERS ON THERMOSTATIC SUPPORTS

Evidently there was some radical difference between the large brass cylinders and the small brass cylinders, and on inquiry it was found that the large brass cylinders were made of bronze—an alloy of copper and tin, while the smaller cylinders were made of an alloy of copper and zinc. Apparently the secret was in the zinc, and to prove this small zinc cylinders were made and tested and found to interrupt the short-circuit instantly under the conditions of test already described; with this distinction, however, that with the pure zinc cylinders there was considerable pitting caused by the arc at the instant of fusing the tin foil, while with the zinc-brass cylinders none of this pitting was noticeable.

Many experiments were now performed with brass terminals of different sizes and shapes and under all possible conditions to determine, if possible, the cause for this phenomenon and, while the search for the cause was apparently fruitless, it was, nevertheless, determined that zinc-brass electrodes were effective in interrupting the short-circuit in a great variety of shapes, the only cases where they failed being when the adjacent surfaces were parallel to each other and when the terminals were more than 1/16 inch apart from each other. This last was one of the most remarkable features connected with this non-arcing property for, contrary to experience, when the brass terminals were brought close

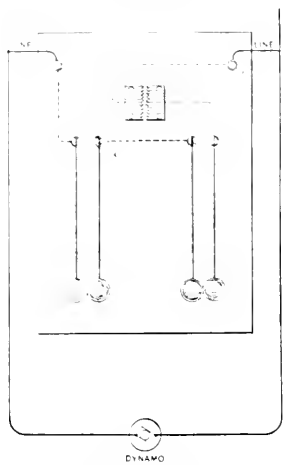


FIG. 9—NON-ARCING METAL BALLS SUSPENDED FROM THIN COPPER RIBBONS

together within 1/32 or 1/64 of an inch the action seemed to be quicker and more pronounced than with 1/16 inch spark gaps, and when the gaps were made larger the non-arcing property ceased altogether. This is well shown in Fig. 7.

A long series of most interesting experiments now ensued which developed the fact that there were five metals having this non-arcing property, namely, zinc, bismuth, antimony, cadmium and mercury. Some of the most important observations made were as follows:—Pure copper would bead, pure zinc would pit, while a combination of these two metals would neither bead nor pit. Mercury was apparently the most effective and quick acting of the non-arcing metals. Under the above described conditions of test with two 1/32 inch spark gaps between amalgamated copper cylinders, short-circuits were interrupted without a noticeable flicker of the lamps connected to the generator, and a horizontal 20 ampere fuse, 10 inches long, would only sag slightly each time the short-circuit took place. However, with the amalgamated electrodes, as soon as the mercury had been vaporized, which was after five or six tests, the short-circuit was maintained and the copper cylinders would bead together, forming a solid mass. Tin seemed to be the most effective metal to destroy the non-arcing property. These experiments should not, however, be dismissed without describing two, which, though they led to nothing in particular, nevertheless emphasized in a most remarkable manner the existence of this non-arcing property under conditions of a very small air-gap. In one experiment four cylinders were connected on thermostatic supports and in series with a spark gap, as shown in Fig. 8. In testing, the cylinders were normally in contact. Tin foil was used to bridge the spark gap, and the short-circuit was instantly interrupted by the non-arcing property asserting itself when the thermostats opened up the two gaps between the four cylinders. One would have ordinarily expected the cylinders to fuse and melt together, but, on the contrary, they separated and opened the short-circuit repeatedly.

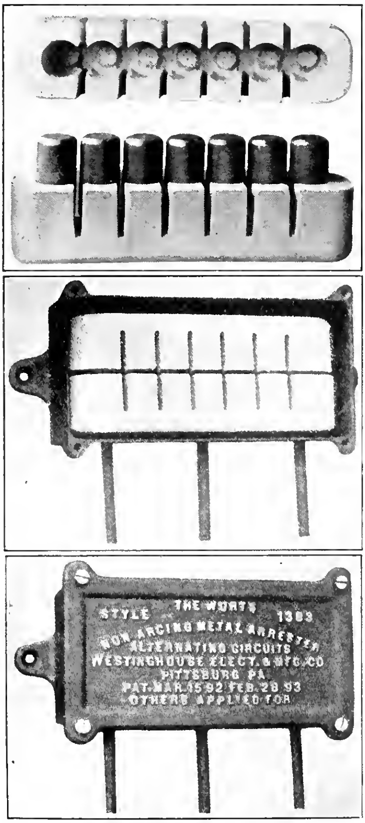


FIG. 10—EARLY WURTS NON-ARCING METAL ARRESTER

Another experiment similar to the above and which, perhaps more than any other, indicated the persistence of the non-arcing property with the smallest possible spark gap is shown in Fig. 9. Non-arcing metal balls were suspended from thin copper ribbons and in series with a spark gap, the balls being normally in contact with each other. On short-circuiting in the usual manner the heat developed between the balls was sufficient to separate them and thereby give the necessary air-gap so that the non-arcing property might assert itself and thereby interrupt the short-circuit. This experiment also was repeated many times with the same result.

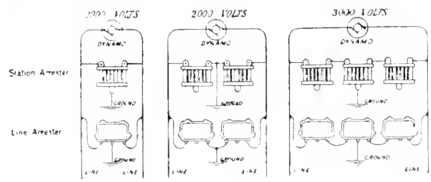


FIG. 11—CONNECTIONS OF STATION AND LINE ARRESTERS FOR CIRCUITS OF 1000, 2000 AND 3000 VOLTS

Thus in a most unexpected way this discovery of the non-arcing metals led to the design of the simple, cheap and effective lightning arrester, without moving parts, which had been sought in the combination of spark gaps on the line and circuit breaker in the station.

In its commercial form this lightning arrester was constructed with seven knurled zinc-brass cylinders, each one inch long by three-fourths inch in diameter and mounted in porcelain receptacles, as shown in Fig. 10. This construction constituted a double-pole lightning arrester with three 1/32 inch gaps intervening on either side between line and ground. For higher voltages additional units were connected in series, as shown in Fig. 11.

(To be continued)

Temperature Tests on Niagara Falls Power Company Generator

T. Spooner
Research Dept.,
Westinghouse Electric & Mfg. Company

AT THE time of their installation the famous umbrella-type generators of the Niagara Falls Power Company were remarkable because of their size and capacity, since they were several times the size of any generators built up to that time. Today they are remarkable because of their marvelous performance, the first having been in almost continuous service for over twenty years. At the time of their installation they taught the world much concerning the generation of electric power. Today they are still teaching us lessons in the art of insulation. For some time it was suspected that the windings of these generators had been operating at temperatures considerable in excess of those assumed by the designers, or considered safe by present conservative practice. The purpose of this article is to recount the methods and results of certain tests recently made to determine the actual temperatures to which the first of these machines has been subjected.

THE first of the Niagara generators was placed in service August 25, 1895, the second a few months later and the third in 1897. There are ten generators of this type in the No. 1 power house shown in Fig. 1. The No. 1 generator, on which the tests to be described were made, has broken down only twice in its twenty years of operation. On February 19, 1909, one of the bars broke down on the routine potential test, and on August 10, 1913, there was a short circuit at the top of the winding at the time of a lightning storm, which made it necessary to replace six long and six short bars, and 24 end connectors. No other replacements in the winding of this generator have been made, except those recently made for the purpose of carrying out the temperature tests.* Every three months 6000 volts is applied for ten minutes to the windings. The operating voltage is 2300.

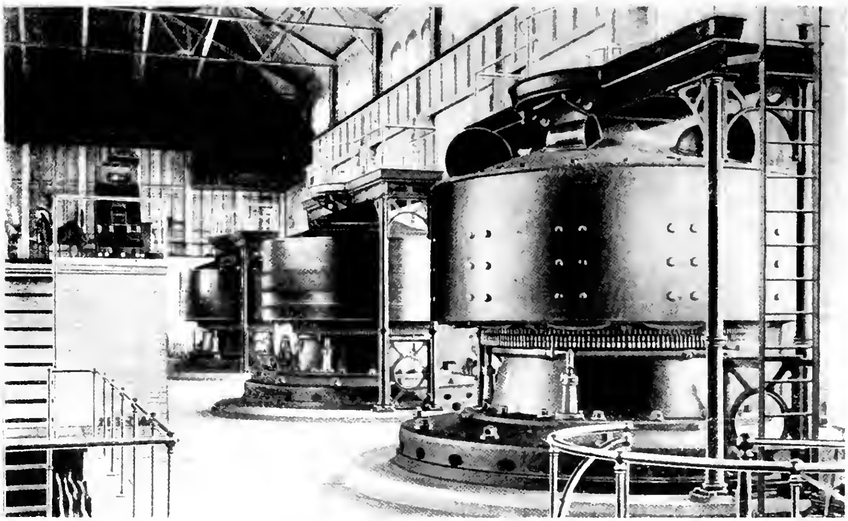


FIG. 1—ORIGINAL INSTALLATION OF NIAGARA GENERATORS

An analysis of the station records for nine typical years shows that during twenty years' service the No. 1 generator has operated for approximately 110 000 hours (up to August, 1915). This is equivalent to 5800 hours operating during each year, 16 hours during each day, 12 years continuous operation, or 30 years for 10 hours daily. It has delivered 280 000 000 kw-hrs. of energy during this length of time, which corresponds to an average load of 2550 kw, or 67 percent of its rated capacity. No other generators of this capacity have been in service for such a length of time.

DESCRIPTION OF GENERATOR

This type of generator differs from the present type of standard generators in that the revolving field is ex-

*See paper on "Mica Insulation," by Mr. F. D. Newbury, *Proceedings A.I.E.E.*, Oct., 1915, p. 2555.

ternal to the stationary armature. The present discussion deals with the armature only, which has two conductors per slot, placed in 187 slots. Each conductor is solid copper 1-11/32 by 7/16 inch. The insulation of the straight bars is made up of mica splittings on a

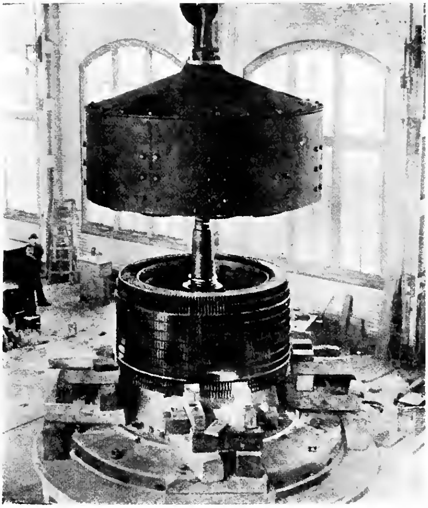
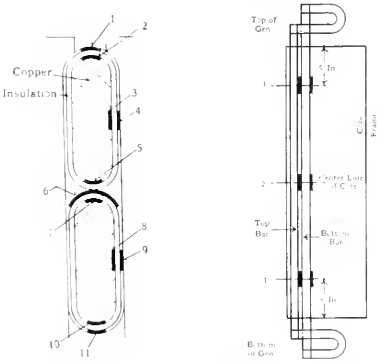


FIG. 2—NIAGARA GENERATOR ARMATURE
With fields lifted for inspection or repair.

cambric base, almost 75 percent of the total insulation being mica. The insulation was wound by hand on the bars and held in place by an outside layer of linen tape. The core is made up of steel laminations bolted together. The induction in the core teeth is about 11 000 gausses—much lower than is common practice today—inductions of 16 to 20 kilogausses being frequently found in



FIGS. 3 and 4—LOCATION OF THERMOCOUPLES IN GENERATOR

modern armatures. The current density at rated current is only 1400 amperes per sq. in. (215 amperes per sq. cm.), while densities of 30 percent greater are common today. However, as will be shown later, the greater part of the copper loss is due to the eddy currents in the windings, so that the actual current densities are much higher than 1400 amperes per sq. in.

TEMPERATURE TESTS

Mr. L. B. Stillwell* in 1901 stated that by the aid of platinum exploring coils placed next to the armature conductors, temperature rises of 65 degrees C. had been measured on these machines, and he estimated that the actual temperatures probably ranged from 85 to 100 degrees C. In the summer of 1913 a resistance coil was placed between the bars in the slot of the No. 1 machine. The limit of the measuring device, 130 degrees C., was exceeded, although the coil was not near the center of the armature. These results looked so interesting that the manufacturers of the machines were consulted, and a series of further tests was outlined.

Method of Obtaining Temperatures—It was decided to use thermocouples for the succeeding tests. A thermocouple consists simply of two wires or ribbons of different materials joined together at one end and having the other free ends carried to some device for measuring voltage. When the junction is heated an e.m.f. is

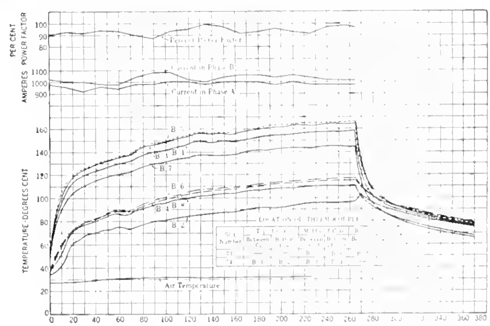


FIG. 5—GRAPHICAL LOG OF TEST OF OCTOBER 2

generated, which is a function of the difference of temperature between the hot and cold ends of the couple, and a suitably calibrated voltage measuring device will read this difference of temperature directly in degrees. Two of the most suitable materials to use for thermocouples are copper and advance, the latter being an alloy of copper and nickel, and these materials were used in the tests. The voltage measuring device was what is called a thermocouple potentiometer,† which is simply a very low reading portable potentiometer, calibrated if desired directly in degrees. Since no current flows through the thermocouple when the potentiometer is balanced, the length and resistance of leads may be varied at will without changing the readings of the instrument.

*"The Electric Transmission of Power from Niagara Falls," *Transactions A.I.E.E.*, Vol. XVIII, p. 445.

†See "Measurement of Temperature in Rotating Electric Machines," by Messrs. L. W. Chubb, E. I. Chute and O. W. A. Oetting, *Transactions A.I.E.E.*, Feb., 1913; also "Experimental Temperature Measurement of Electrical Machines," by Mr. O. W. A. Oetting, in the JOURNAL for Feb., 1914.

The thermocouples themselves were made of ribbons 0.25 by 0.005 inch, spot-welded together at one end and insulated with micarta paper shaped to fit the slot and bars. Six special armature bars, made up with these couples suitably attached, as shown in Fig. 4, and

TABLE I—FINAL TEMPERATURES, DEGREES C.

	Top of Core		Center of Core		Bottom of Core	
Armature Slot No.	Between Bars	Between Core and Bar	Between Bars	Between Core and Bar	Between Bars	Between Core and Bar
11			164.8	112.8	140.0	103.3
12	154.4	101.3	162.2	113.8		
73			166.5	117.2	145.0	111.0
74	158.3	96.5	164.8	115.7		
135			160.7	122.5	144.7	102.7
136	153.2	94.1	165.0	99.5		

Final air temperature = 33 degrees C.

with practically the same insulation as that used for the original generator windings, were substituted for the old bars in three pairs of slots equally spaced around the armature. In one slot of each pair couples were located at the middle and five inches from the top of the core, and in the other at the middle and five inches from the bottom of the core. For each location of each pair of conductors couples were placed between the two bars and between the bottom bar and the iron. Couples *6* and *11* of Fig. 3 also indicate the location. The couples were all placed in phase A.

First Thermocouple Tests—On October 2, 1914, the first run was made with the couples installed. The water wheel was somewhat clogged with pulp wood and full-load current could not be obtained at that time except by lowering the power-factor. After the run the water wheel was cleaned and another run was made at 1000 amperes per phase on October 3, 1914. The graphical log of this run is given in Fig. 5, and Table I gives the final temperatures attained.

It will be noted that the temperature between coils shown in this test was much greater than that between coils and core. Also the temperatures were higher than would be expected from a consideration of the copper

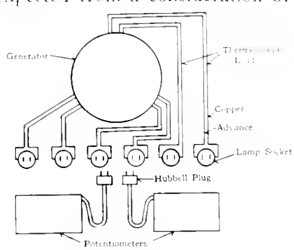


FIG. 6—DIAGRAM OF CONNECTIONS

current densities, due to the load current. It is evident, then, that the iron was running cooler than the copper and, from a consideration of the eddy currents induced by the armature flux, that the temperatures of the top windings were greater than those of the bottom. Therefore, this series of tests did not give the maximum temperatures of the windings, but only the mean temperature between the top and bottom windings. It was, therefore, decided to make further tests which would show the actual maximum copper temperatures.

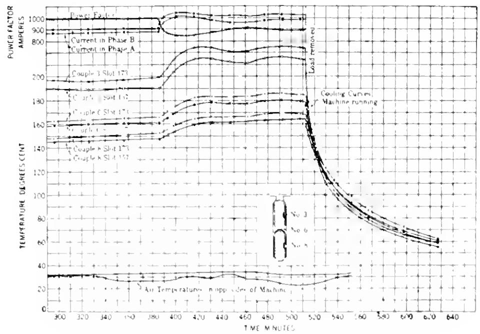


FIG. 7—GRAPHICAL LOG OF TEST OF FEBRUARY 15

Second Thermocouple Tests—For these tests six bars were provided for three slots. Four bars for two slots were insulated with practically the same insulation as that used in the original machines and the couples located at the center of the armature in the positions shown at *3*, *6* and *8*, Fig. 3, couples *3* and *8* being in actual contact with the copper, and couple *6* being inserted simply to check the results of the previous runs.

TABLE II—FINAL TEMPERATURES, DEGREES C.

	870 Ampere Load			980 Ampere Load		
Armature Slot No.	Bottom Bar	Between Bars	Top Bar	Bottom Bar	Between Bars	Top Bar
157	147	161	190	164	179	214
173	152	166	199	168	185	224

Final air temperature = 30 degrees C.

TABLE III—FINAL TEMPERATURES, DEGREES C.—SLOT 17

Couple	700 Amperes Load	900 Amperes Load	1000 Amperes Load
1	117	157	175
2	153	214	243
3	155	217	246
4	131	171	189
5	155	216	244
6	132	176	197
7	123	164	183
8	123	164	183
9	119	151	166
10	124	165	184
11	120	155	170

The two bars for the third slot were located as shown by couples *1* to *11*, Fig. 3, at the center of the armature. Since there were so many couples in this slot, the insulation was made thinner than normal in order to provide room for them.

Due to the fact that some of these couples were in contact with the copper and that readings were to be obtained with normal load and voltage on the machines, it was necessary to take special precautions in making the tests. In the first place, it was necessary always to

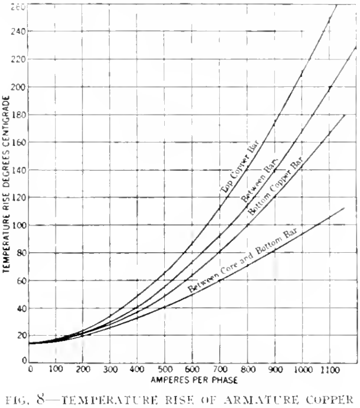


FIG. 8—TEMPERATURE RISE OF ARMATURE COPPER

have the various couples insulated from each other, and in the second it was necessary to protect the observers, as the voltage might go to over 1000 volts above ground. Each pair of couple wires was brought to an ordinary lamp socket secured to the testing table, in which was placed the female part of a Hubbell plug. Two potentiometers and two observers were used, as it was desired to secure rapid readings during the cooling curve period. The male portion of a Hubbell plug was connected by flexible leads to the terminals of each potentiometer. In this way either potentiometer could be connected quickly and easily to any thermocouple and no two thermocouples could be connected together. The observers stood on an insulated platform. There were 17

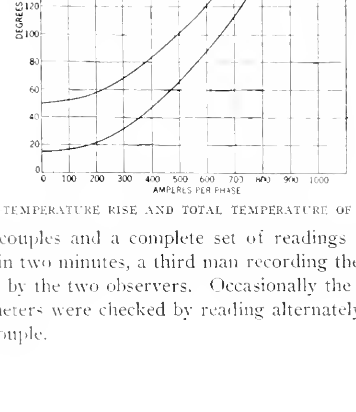


FIG. 9—TEMPERATURE RISE AND TOTAL TEMPERATURE OF TOP BAR

thermocouples and a complete set of readings was obtained in two minutes, a third man recording the results as read by the two observers. Occasionally the two potentiometers were checked by reading alternately on the same couple.

On February 12, 1915, a run was made at 680 amperes, and on February 13, 1915, one at 870 amperes, increased after steady temperature conditions were reached to 980 amperes. Fig. 7 gives the last portion of the graphical log of this test and Table II the final temperatures, for the bars having standard insulation only. Table III gives the final temperatures of the bars having special thin insulation. Fig. 8, which was constructed from the data of these tests, shows the temperature rise for the various parts of the winding with increased load, and Fig. 9 shows the temperature rise of the top bar and the total temperature, assuming the air at 35 degrees C., which is a fair average for this particular installation.

DISCUSSION OF RESULTS

The large difference in temperature between the top and bottom bars was due to excessive eddy currents in the copper. In modern machines these large differences are eliminated by using more conductors per slot.

The iron temperatures are low since the inductions

TABLE IV—OPERATING DATA

Length of Service in Hours	Load Amperes per Phase
40 000	600 to 700
13 800	700 to 800
8 200	800 to 900
2 600	900 to 1000
100	1000 to 1100

TABLE V—RANGE OF OPERATING TEMPERATURES

Length of Service in Hours	Range in Operating temperature Based on 35 Deg. Air
40 000	120 deg. to 145 deg.
13 800	145 deg. to 175 deg.
8 200	175 deg. to 210 deg.
2 600	210 deg. to 245 deg.
100	245 deg. to 285 deg.

are low, and consequently the iron losses are small The reason that the temperatures of the couples between bars is not the mean of the two bar temperatures is that couples *6*, Fig. 3, are wrapped around the bottom bar. It is interesting to note the very rapid cooling of the copper when the load was disconnected, as indicated by the graphic log.

Some interesting things are shown by Table III. The maximum temperature of 246 degrees C. was actually recorded at 1000 amperes. Couples *1* and *2* show a temperature gradient of 68 degrees for the insulation at the top of the top bar. A comparison of couples *2*, *3* and *5*, also *7*, *8* and *10*, of Fig. 3, show great uniformity, as should be the case, since the three couples of each set are in contact with the same bar. As far as is known, this is the first time that actual copper temperatures have been obtained on a generator under load conditions.

From the station records, Table IV has been prepared to show the length of service in hours with reference to the load in amperes per phase. Substituting for

the load in amperes the temperatures in degrees as obtained from Fig. 9, Table V is produced. When it is considered that the standardization rules allow only 125 degrees C. for the maximum operating temperature of class *B* insulation, which is the class into which this insulation falls, this record is truly remarkable. When it is considered also that the windings of this machine have never failed because of the deterioration of the mica insulation due to temperature, is it not evident that these Niagara Falls machines are still able to teach us something concerning the generation of electric power.

The reason that this insulation is able to stand such service is as follows:—Temperatures of 200 degrees C. and more will in time destroy cambric, linen, paper, or any of the other binders comonly used for mica insulation, but the mica itself is not changed by a temperature under 500 or 600 degrees, or even higher in some cases. An examination of some of the old bars removed from this machine showed that while the cambric was burned in some places quite to a powder, yet the mica was as good mechanically as when new. As pointed out by Mr. Newbury in the paper referred to, it is possible to destroy all of the binding material and still hold the copper tight in the slots, since the mica, due to its elasticity, acts as a sort of spiral spring. Of course, if the binding material is too great a proportion of the total, or if the insulation is not wrapped tightly enough, the loss of the binding material due to heat may allow the coils to vibrate and in time ruin the insulation by abrasion. However, if these old Niagara generators with their hand-wound coils can stand such severe temperature conditions for 20 years, modern machine-wound coils should do even better. The poorest of these Niagara coils stood a voltage of 22 000 before breakdown, and that on an insulation which had been in service for over twenty years, had operated at temperatures of from 245 to 285 degrees C. for at least 100 hours, and was originally designed for a working voltage of only 2300.

ENGINEERING NOTES

Why Poles Are Laminated

Due to the slots in the armature of a direct-current machine, the flux is not evenly distributed over the armature surface, but is bunched at the tops of the teeth, as shown in Fig. 1. This bunching of the flux causes an unequal distribution over the pole face, the areas above the teeth having a greater flux density than those above the slots. These tufts of flux, in passing over the pole face, set up eddy currents which tend to flow in an axial direction over the length of the pole, causing heating of the pole face.

When solid poles are used, a large air-gap and narrow armature slots are required in order to reduce eddy currents to a minimum value by causing a more even distribution of flux over the pole face. While these remedies have the desired effect, they also have their disadvantages. The narrow slots give a poor space factor for the armature winding, which means a large machine for its rating. The large air-gap necessitates the use of a strong field to overcome the gap reluctance, which results in the use of a greater amount of copper in the field windings than would be necessary with a small gap.

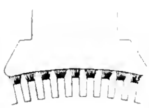


FIG. 1

The laminated construction of the poles limits the path of the eddy currents to the width of the lamination, and so prevents the currents from adding together as they do in the solid poles. This reduces the eddy losses and, therefore, the temperature rise in the pole face. The value of laminations in the reduction of eddy current losses is well seen in the fact that, other things being equal, these losses vary directly with the square of the thickness of the laminations. By reducing the eddy losses the laminated pole permits of the use of wider armature slots and a much smaller air-gap than can be used with a solid pole.

In addition to the above advantages the laminated construction assures a uniform grade of metal in the pole, while the interior of a cast steel pole may be spongy. Because of this fact and the lower temperature rise, due to decreased losses, the total flux can be greater in a laminated than in a solid pole.

B. H. LYTLE

Rotating Field Construction on Alternators

Rotating armature generators are limited to voltages not exceeding 2200 volts on account of the difficulty in insulating the armature coils, as well as insulating the collector and brush rigging. They are also limited to relatively small armature currents by the difficulty in collecting large currents. Neither of these limitations is insurmountable, but the expense of overcoming them, together with the greater maintenance cost of collector rings and brushes, make the stationary armature type preferable.

Considering the revolving field generator, it has relatively small field currents with two collector rings instead of the larger, higher voltage, load currents with three or four rings. The danger of insulation breakdown of the armature coils is less with stationary armature coils, for they are free from centrifugal stresses of the rotating part. It is easier to support the field coils against these stresses than the armature coils. With the fan action of the rotating field and the large entrances for air between the field coils, the rotating field generator receives better ventilation.

The armature formed the limit in size until the change was made to the rotating field generator, and this change made the unit smaller in diameter and width; the latter gain being due to the shorter coil extensions with the relatively larger coil diameters.

Finally, the development of the revolving field generator has made all generators (except the very smallest) lower in cost, as well as more reliable in operation, and has made it possible to build machines for higher voltages and speeds than would be possible with the other type.

R. KELLY

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1279 — Magnetizing Current — What would be the magnetizing current of a bank of three 500 k.v.a., 50 cycle, 6600 volt, single-phase transformers? Would there be much difference between the magnetizing currents of the above bank, total k.v.a. 1500, and one of, say fifteen transformers of 100 k.v.a. each? A test was taken of a bank of three single-phase transformers of 1500 k.v.a. total capacity, and it worked out to 6.2 kw-hr. Is that anywhere near what it should be for the bank? Integrating wattmeter readings were taken before and after the test. Is that a reliable method of testing for the magnetizing current of a bank of transformers?

S. S. (SOUTH AFRICA)

The magnetizing currents of transformers vary considerably for units of the same capacity, voltage and frequency. Their value depends upon the amount of iron in the core, the permeability of the iron and upon the flux density at which the core is worked. Transformers of 500 k.v.a. capacity, 6600 volts, 50 cycles, would probably have a magnetizing k.v.a. of five percent of their rated output. On this assumption a bank of three 500 k.v.a. units, with the above characteristics, would draw magnetizing currents of approximately 6.5 amperes per line when supplied from the 6600 volt side. Fifteen 100 k.v.a. transformers usually require a considerably larger magnetizing k.v.a. than three 500 k.v.a. units of the same voltage and frequency, but this is not necessarily the case, as some of the factors mentioned in the first paragraph may be of such values as would keep the magnetizing k.v.a. the same, or even less, than that required for the three 500 k.v.a. units. Wattmeters are not suitable for measuring magnetizing currents of transformers, as these instruments measure the product of three factors—current, voltage and the cosine of the time angle between the current and voltage. The time angle between the magnetizing current and the voltage is 90 degrees and its cosine is zero. Therefore, since one of the factors is zero, a wattmeter will not indicate or record magnetizing k.v.a. The recording wattmeter in this test recorded the true energy; that is, the no-load losses of the bank of transformers. The value stated (6.2 kw) is about an average no-load loss for a bank of transformers of this rating. The method of determining magnetizing k.v.a. that is generally used is to measure the exciting current with ammeters and the no-load loss with wattmeters, and from these two measurements calculate the magnetizing k.v.a. The magnetizing k.v.a. is the

$$\sqrt{(\text{Exciting k.v.a.})^2 - (\text{no-load loss in kw})^2}$$

The no-load loss of the bank can be measured with either indicating wattmeters or with integrating wattmeters, as was done for the three 500 k.v.a. transformers. The exciting k.v.a. is determined by measuring the currents in the three primary line leads and then multiplying the sum of these three ammeter readings by the primary line voltage and dividing by $\sqrt{3}$. The secondaries of the bank should be open while these tests are being made.

J. F. P.

1280—Truck Equalization — (a) Why is it that on some locomotives the two trucks are different in that one is cross-equalized and the other longitudinally? (b) What purpose do these equalizer bars serve? (c) Have they any connection with the increased pressure on the rear wheels during acceleration? (d) Can you give references to articles or books on electric locomotive truck design?

L. S. C. (NEW YORK)

(a) The purpose of the equalization system on a locomotive is to maintain

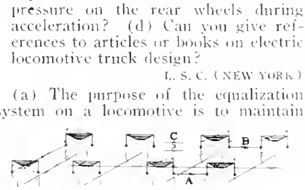


FIG. 1280(a)

approximately the correct journal loading on the various axles and at the same time to allow a relatively large vertical displacement of the various wheels, due

FIG. 1280(b).

to uneven track. It is also necessary that the locomotive be in stable equilibrium both about its longitudinal and transverse axes. One scheme of equalization for obtaining the above result on a locomotive having two four-wheel trucks is shown in Fig. 1280(a). The axles of the No. 2 truck are equalized independently on each side and, therefore, the weight is divided evenly between these two axles. This truck, however, is not stable longitudinally, having in effect only two points of support, at *A* and *B*. If the No. 2 truck were not otherwise restrained, it would be free to rotate about an axis through *AB*, the equalization system assuming the position shown by the dotted lines for rotation of the truck in a counter-clockwise direction. It is, therefore, necessary to restrain this truck from rotation about the axis *AB*, which may be accomplished by long side bearings having a small clearance and by connecting this truck with the No. 1 truck through the articulation hinge shown at *C*. The No. 1 truck is stable about both a transverse and longitudinal axis, but the distribution of weight between the two axles will not be maintained so well as in the No. 2 truck, as the two axles are not equalized together. The purpose of the cross-equalization on the No. 1 truck is to allow one axle to assume a position not parallel with the other, as shown by the dotted lines, without any one wheel losing its load and being thereby liable to derailment. The effect approaches that of a three-point suspension. There are other methods of obtaining stability about a transverse axis than that shown on the No. 1 truck, such as using a low center pin, and long semi-elliptic springs hung from the equalization system, Fig. 1280(b), or by the use of spring-loaded friction plates, Fig. 1280(c). (b) The purpose of the equalizer bars is to connect the various wheels and axles together so as to give as nearly as possible the effect of a three-point support to the running gear. (c) In cases where the axles are equalized together, as in the No. 2 truck, there will be no transfer of weight from the leading to the trailing axle during periods of high tractive effort. There will, however, be a transfer of weight from the leading to the trailing truck and from the front to the trailing axle on the No. 1 truck, as these axles are not equalized. (d) See articles by Mr. G. M. Eaton on "Principles of Equalization," Dec., 1910, and "Weight Transfer," March, 1911.

H. K. H.

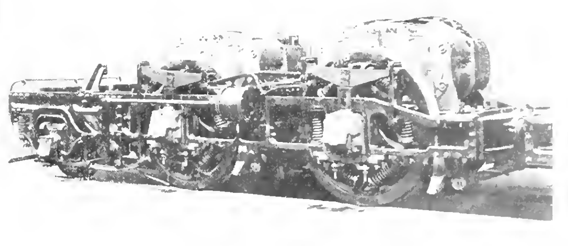


FIG. 1280(c)

1281—Electrolytic Rectifier—I wish to construct an electrolytic rectifier with iron and aluminum electrodes. I wish to reduce from 115 alternating-current volts to 10 to 15 direct current and three to five amperes capacity. Please tell me size of electrodes, size of jar and percent phosphate solution. Referring to No. 141, Sept. 1908, could I use an autotransformer in place of choke coil and get the desired voltage by taking taps from autotransformer to give desired direct-current voltage, or will I have to reduce on the direct-current side with resistance?

C. W. B. (PENNA.)

It is possible and advisable to use an autotransformer in place of the choke coil shown in No. 141(a). The required alternating voltage will be something over double the direct voltage, depending on the efficiency of rectification. For self-cooling and continuous operation the size of the aluminum plates should be not less than seven square inches per ampere, and the lead or iron electrode should be two or three times as large. With the connections shown in Fig. 819(a), Feb. 1913, the iron plate need be

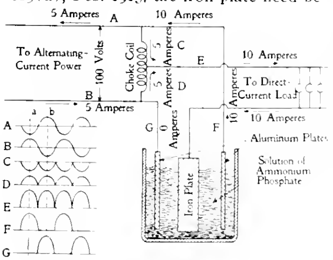


FIG. 141(a)

only the same size as the aluminum plate. The amount of electrolyte should be sufficient to provide at least one square foot of radiating surface of the containing vessel per ampere direct current. The amount of electrolyte and the size of aluminum and iron plates may be greatly reduced if some means is provided for artificial cooling, as, for example, circulating the electrolyte through a cooling vessel. The electrolyte should consist of a saturated solution of pure neutral ammonium phosphate. C. R. R.

1282—Static in Paper Machines—We are troubled with static electricity in our paper while undergoing the calender-finishing process. Grounding the calender frames and stretching copper wires across the path of the finished paper, as it leaves the front side of the calenders, takes care of the static discharge, which in many instances is very excessive. But this scheme does not seem to neutralize it altogether, for we find that after the paper has been cut into sheet size there is still present electricity in the paper when undergoing the second and third calender operations, even in spite of the fact that the paper has stood for a number of days before the finish has been completed. Please enlighten me on the theory of this subject; also if there is any reliable apparatus that would neutralize it more, or completely if possible. T. K. (QUEBEC)

Very little information is available regarding the theory of the production of static electricity on paper machines, but it is generally understood that it is due to friction of the paper and the calender roll, although there are various other factors, such as atmospheric conditions, temperature of the rolls, etc., which affect the production of static. The speed of the paper is also an important item in the production of static, and the most trouble is generally experienced on high-speed machines. The scheme of discharging the static by means of a wire across the sheet has been used with various modifications in most mills. A more complete discharge of the static electricity by this method is obtained by employing several wires together with numerous brushes of tinsel bearing on the paper. None of these methods, however, completely discharge or neutralize the charge on the paper, but they are generally sufficient, especially where the paper is shipped in roll. Printing plants experience a large amount of difficulty with static electricity, especially during the winter; and many presses are forced to operate at half speed for a considerable portion of the time when starting up, and in many cases several hours' production will be lost during the week due to this trouble. In view of this fact, a large amount of study and experimentation has been made with a view of eliminating this feature in printing plants. The only really satisfactory device now on the market is an equipment which produces an extremely high voltage which is discharged from a special insulated bar across the surface of the sheet of paper. Regardless of the theory of exactly how this high-voltage alternating current neutralizes the static discharge, this equipment gives very satisfactory results and practically eliminates the static charge on the paper. To obtain continuous and satisfactory operation from this equipment, it is necessary, however, to give the high-voltage discharge bar systematic and careful cleaning to remove lint or other foreign material. C. W. D.

1283—Wet Induction Motor—A 40 horse-power, three-phase, 60 cycle, 2200 volt motor was left out in the rain over night. (a) Would it be safe to run this motor without drying it? (b) How hot should an oven (steam heated and ventilated) be kept to insure a thorough drying? How could I tell when the motor was thoroughly dried? (c) Which would be the better way—drying in a steam-heated oven (highest temperature available 105 degrees C.) well ventilated, or the electric method? (d) In drying electrically why is it customary to use 90 degrees C. by thermometer; will 90 degrees C. drive out the moisture? (e) Using a 50 volt Weston voltmeter and 30 volt (dry cells) and the formula $R = \frac{V - d}{d} \times R_{Vm}$, I continued the drying in the oven until I got a leakage reading of a little less than five volts—assuming 50 ohms per volt, $V = 30$ volts, $d = 5$ volts, $R_{Vm} = 2500$ ohms, whence, from the formula, $R = 12\,500$. Did I dry it long enough to feel safe? The motor has since run satisfactorily for two months. A. G. W. (WISC.)

(a) It would not be safe to run the motor without drying it out. This is sometimes done, but always with risk. (b) In a drying oven externally heated a temperature of 105 degrees C. could be maintained indefinitely without injury to ordinary cotton or fibrous insulation. (c) Either method is satisfactory. The oven method dries from the outside *in* and the electric method from the inside *out*. The oven method is somewhat quicker in many cases. (d) In drying electrically 90 degrees C. should be used as a limit, because there may be internal local hot spots which are inaccessible to the thermometer which are somewhat higher. The new rules of the A.I.E.E. (July, 1915) state that it is proper to allow 15 degrees C. for this difference in hot spot temperature, and this added to 90 degrees C. makes 105 degrees C. as a limit on insulation of this class. A. M. D.

1284—Size of Transformers—Please give me the size and characteristics of the largest transformers which have been built up to the present time. A. R. W. (QUE.)

The largest transformers so far built, considered from the standpoint of k.v.a. rating, are the two 14 000 k.v.a. units of the Shawinigan Water & Power Company at Shawinigan Falls, Quebec. These transformers are three-phase, 60 cycle units, stepping up from a generator voltage of 6600 to the line voltage of 100 000 volts. The low-voltage windings are connected in delta; the high-voltage windings are connected in star, with provision for grounding the neutral point through a resistance. W. M. D.

1285—Uncertain Action of Electrically-Operated Circuit Breaker—Considerable trouble was experienced with a line of electrically-operated circuit breakers opening up whenever a slight jarring occurred, such as the closing of an adjacent breaker. These circuit breakers had been adjusted to operate over a range of 70-140 volts, and it was only after they had been closed on the higher voltages that trouble occurred. It was eventually found that the mechanism closed properly, the latch engaging accurately with the catch. On breaking the current in the closing coil, however, the tripping core gave a slight kick, hitting the latch hard enough to partially disengage it and render the operation of the circuit breaker uncertain. Please explain this action. Fig. 1285(a) indicates the arrangement of coils, cores and cast iron supporting frame. The trouble was cured by lowering the tripping core slightly. J. P. (ONTARIO)

The cause undoubtedly is that a current is induced in the trip coil winding by the collapse of the magnetic lines when the current is cut off from the closing coil. The trip coil circuit is probably completed through the red indi-

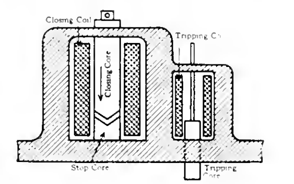


FIG. 1285(a)

cating lamp, as is the case in standard method of connections. The current induced is sufficient to raise the trip magnet core when set so that the air-gap is comparatively small. An increase of air-gap of the trip magnet will probably overcome the difficulty. H. S. M.

CORRECTION

In the JOURNAL for March, '16, the columns at the top of p. 124 should be interchanged.

FINANCIAL SECTION

PUBLIC UTILITY BONDS

Their Relation to Physical Value and Earning Power

In raising new capital corporations have three principal classes of securities which they offer to the public—bonds, preferred stock and common stock. In addition, at times, corporations secure temporary loans from banks or large investors or issue short-time notes, but in the end these obligations are converted into one or more of the three principal classes of securities. Bonds or short-time notes are evidences of indebtedness, and the holder of them stands in the relation of creditor to the issuing corporation and, under the law, has the right to enforce payment as in other forms of debt. The holder of common or preferred stocks stands in the relation of a partner to the corporation and, therefore, must share the hazards of its business to a much greater extent than does the holder of its bonds. This fundamental difference between the relation of the bondholder and that of the stockholder to the corporation must always be kept in mind by the investor. In future articles the relation of the holder of preferred and common stock to the issuing corporation will be dealt with at length, while in the present article particular attention will be given to the relation of the holder of bonds or their equivalent.

In the modern corporation the fundamental character of a bond has been largely changed. In former years, the amount of the mortgage under which the bonds were issued was supposed to be fully or more than covered by the property which was mortgaged as security for the bonds and, in case of default, the holder of the bond had the right to feel that at a sale of the mortgaged property he would receive the full face value of his bond. In other words, there was supposed to be behind the bonds a value of physical property equal to, or larger, than the entire amount of bonds outstanding on it. Today this rule holds good only with real estate mortgages or bonds and not with corporation bonds. The present-day corporation bond should be viewed as largely a lien on the earning power of the issuing corporation, instead of on its actual physical property. It is probable that in the case of the greater part of the large industrial or public service corporations of the country that, under a forced sale, their physical property would not bring an amount sufficiently large to cover their funded indebtedness. It is, therefore, of the utmost importance that the investor in the bonds of a corporation should have the information which will enable him to know that the sustained earning power of the issuing corporation is such that there will be no danger of its earnings dropping to a point where it would have to default on its bond interest. A financial statement of the company covering a period of years, showing net earnings available for bond interest in each year, is the best guide to this and, in addition, the nature of the business also should be considered, as in some lines earnings are subject to great fluctuations, while in other lines there is but little change from year to year. Corporations which furnish necessities of life may be put in the latter class, and it is for this reason that bonds of long-established gas and electric light and power companies are coming into such favor with investors, as their record of stability of earnings is not excelled by that of any other class of corporations. Water supply companies may be put in the same class and to a less extent electric street and interurban railways. To the average investor of today the earning record of a company is of more importance than the physical property behind its bonds, so long as that property is well maintained and kept in condition to give good service and thus add to its earning power. In the case of the long-established gas or electric light and power company, earnings should show at least twice the bond interest earned, while in the case of more recently organized companies, which have a good field for development of service and consequent increase of earning power, earnings of one and one-half times or one and three-quarter times the bond interest may be accepted. It will be found, however, in buying such bonds that the smaller earning power on the bonds is reflected in a lower price for the bond. For this reason there are many investors who purchase the bonds of these companies with the smaller earning power, where they are satisfied that this margin of safety

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above bond interest will steadily be increased, as it means that, not alone will they be able to buy the bonds on a larger income basis, but at the same time will secure a profit in the advance in the price of the bonds as the earnings of the company continue to grow and the margin of safety above bond interest becomes larger.

Bonds issued by companies having a long record of sustained earning power and a large margin of safety above interest requirements, and which have been outstanding for some years, are known as "seasoned" bonds, while the bonds issued by newly organized companies, which have not as yet proved their ability to show a good average margin of safety above interest requirements for a period of years, are "unseasoned" bonds and sell at a much lower price than the seasoned bonds. This factor of earning power, instead of value of physical property covered by the mortgage, is now being generally recognized in the indenture securing bond issues. In substantially all issues of light and power and street railway or other public utility bonds made in the last few years it is provided that additional bonds may only be issued when earnings applicable to the payment of interest on the bonds already outstanding and those about to be issued bear a certain relation to the interest requirements, such as one and one-half times or one and three-quarter times the amount required for interest payments over a certain previous period, usually that of one year. This provision is now almost always placed in indentures securing second mortgage bonds or debentures, but at times is also included in the indentures of first mortgage bonds. Mortgages also usually contain a restriction that bonds issued under them shall be issued only to 80 or 85 percent of the cash cost of the construction or new property for which the bonds are issued, the remaining 15 or 20 percent being provided for out of income of the corporation. This provision is usually found in first mortgage bonds, and often the mortgages contain both the restriction as to the amount of bonds to be issued for new construction and that regarding earnings available to pay interest on the bonds. In regard to the statement as to physical property, a qualification must be made that the actual cash put into the properties is almost always more than the amount of bonds outstanding but, as the property covered by the mortgage has been created for a special purpose, it is of small value unless utilized for that special purpose, and it would sell for but a small part of the cash actually invested in it in case it cannot make the earnings required to pay a return on the money invested; so in the final analysis it is earning power and not physical property which is the real value behind the modern day corporation bond.

An electric light and power plant in which millions have been invested would sell for only scrap value if it were abandoned for generation of power, and the same is true of a gas plant. In case operation of an electric street or interurban railway, or of a steam railway, is given up and the property offered for sale, its value is only that of scrap to the purchaser unless it is bought to be operated for the purpose for which it was built. So that, as already said, it is to earning power and not so much to physical value of property behind his bond to which the investor should pay particular attention in making his selections of investments.

While bond indentures, or mortgages, are usually drawn along similar lines, there are apt to be differences which, under some circumstances, would be of much importance to the holder of the bonds. Sometimes it is provided that in case of default in interest, the issuing company has from three to six months to make good the default before foreclosure can be enforced. Another is that a certain percentage of the amount of outstanding bonds must make application to the trustee of the mortgage before foreclosure proceedings can be taken. This provision also is of much importance to the small investor. This percentage varies from 20 percent of the bonds up to as high as 60 percent, and it may be seen that it might often shut out the small investor completely in case of default as, if the holders of the large amounts of bonds do not consent to foreclosure proceedings, the small holder would be powerless to enforce his lien. It is well, whenever possible, that the investor ask for a copy of the mortgage under which the bonds being investigated are issued. The bond salesman or bond house should have a copy and, if not, one may easily be obtained, as the issuing corporation always has a number of copies printed for just such a purpose. If the investor cannot understand the terms of the indenture he should ask his banker or some man well informed in investment matters to explain the provisions of the mortgage to him.

Priority of lien also has much to do with the value of a bond, and this should always be inquired into. If the investor is buying a first mortgage bond, he should satisfy himself that it is a first lien on the property and earnings of the issuing company, and also should do the same in regard to any other grade of bond which he is thinking of buying. There are more varieties of bonds than there are products of a widely advertised pickle manufacturing firm, and the investor should therefore be certain which one of the more than 57 varieties of bonds he is buying. Any responsible bond house or bond salesman will furnish this information, and if for any reason it is not furnished, then it would be best to leave that particular bond severely alone. In a succeeding article these different varieties of bonds will be described and, so far as possible, the investor will be told how to differentiate between a prior lien, a first mortgage, a collateral trust, a first lien, a second, third or other mortgage and the other varieties of bonds usually sold to investors. In regard to public utility bonds, to which this series is primarily devoted, it may be said that the financial organizations of the corporations issuing them are much less complex than are those of the steam railways or of many of the large industrial corporations and the investment value of their bonds is much more easily understood by the average investor. So far as possible the public utility corporations are simplifying their corporate organizations and striving to refund their underlying mortgages by one general mortgage, thus getting rid of a multiplicity of underlying issues. The attitude of the investor has been to some extent to blame for the many underlying issues. Not so long ago, the average investor, as well as many bond houses, looked with suspicion on the present-day "open-end mortgage," or a mortgage which in effect gives the corporation an unlimited authorized bond issue. In former days, before the great expansion of public utility service was realized, the bond houses favored small authorized issues of bonds. This was soon found to be a handicap on the public utility corporations. Many a utility corporation has had its growth in business and service stunted and its earning power greatly retarded by the fact that it was confronted with the necessity of raising additional capital to provide for the imperative demand for extension of service, but at the same time found it had exhausted its entire authorized bond issue. In this case it had but two alternatives if it was to continue to grow. One was to create a second mortgage on the property, with the knowledge that it would have to sell these bonds at heavy discount because they were not a first lien; the other was to create a new first and refunding mortgage and sell under it bonds enough to retire its out-

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standing bonds probably at a large premium, and to produce, in addition, the capital required for its other corporate necessities. The public utility business, especially that of the electric light and power companies, expanded at such a rate that these small mortgages were soon outgrown, and the public utility men and the bond houses saw the mistake that had been made in so limiting the power of the companies to secure new capital for enlargement of their generating, transmission and distributing systems. Then came the "open-end" mortgages of large amounts, with the issue of bonds under them carefully safeguarded by restrictions in regard to earnings and to investment of the proceeds of the bonds in not more than 80 percent of the cash cost of new construction.

This is the reason that now the investor often hears of the creation of a first and refunding mortgage by a company, relatively unimportant, having an authorized amount of bonds running from $25 000 000 to $50 000 000, and sometimes even more. This does not mean that the company is going to issue anything like the authorized amount of bonds, but only that it is taking care to prepare for the future. It may make an initial issue of $1 000 000 of bonds under the new mortgage, but it has, in case of need, a reserve of authorized bonds on which to draw, with, as already stated, the issue of these additional bonds carefully protected by stringent provisions in the mortgage. For this reason an investor need not become alarmed when he sees notice of the creation of such a mortgage by a company in which he has investments. If he holds bonds under a prior mortgage they have a lien ahead of the bonds to be issued under the new mortgage, and the only way in which they may be retired is either by maturing or by calling, if they contain a provision for call, usually at from 1 to 5 percent above their face value.

The light and power business has grown, and is growing so rapidly, that it is imperative that the light and power corporations make ample provision for the capital requirements of the future, and it is to do this that they are creating the new "open-end" mortgages of large amount. As stated heretofore, the writer firmly believes that there are no better investments, especially for the man of limited means, than the securities issued by public utility corporations, more particularly those of electric light and power companies. While street railway securities to some extent were affected by the loss in earnings due to jitney competition in some localities and to general business depression the country over, their earnings are now showing large average gains and they are regaining the favor in which they were formerly held. In fact, now is a good time to buy electric railway bonds of approved earning power, as they are selling at substantially lower prices than will be the case within a year or two. As their earnings recover from the depression of the past two years their securities will advance, and it would be well for the investor not to neglect some of the bargains which may now be secured in first mortgage bonds of electric railways.

But it can be said that there are no better investments in the field of public service corporations, or in any other field, than those of the electric light and power companies. While at present there are approximately $844 500 000 of steam railway bonds on which the interest is in default, and quite a substantial amount of electric railway bonds, there is not a single important light and power issue on which the interest is not being regularly paid. In the last two years there have been no receiverships for any important light and power companies and, while some of the small companies, organized by men inexperienced in operation and not versed in financial affairs, have failed, the light and power companies of the country as a whole have continued prosperous. More than that, they have been able to earn a good return on the new capital invested to meet the growth of their business. Railroad statistics show that of the $5 000 000 000 new capital invested in steam railroads since 1910, the increase in earnings due to the investment of this new capital has been at a rate returning

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but about one percent a year on this immense outlay. It may thus easily be seen why almost $845 000 000 of steam railroad securities are in default. At the same time the light and power corporations of the country have invested hundreds of millions of dollars in extensions of their generating, transmission and distributing systems and have been able to show increased earnings of close to eight percent a year on the additional capital invested. And again, it may thus easily be seen why the light and power corporations have been able to maintain their payments of interest in that period to the holders of their bonds.

Often the question is asked why the corporations of the country, especially the public utility corporations, are constantly going to the public for additional supplies of capital. The answer may be found in the steady increase in public utility earnings. For each dollar of new business secured by an electric light and power company it is estimated that its capital requirements will be $5; for each dollar of new business of electric railways the average of new capital required will average about $6; for the gas company it will take between $4 and $5 of new capital to care for each dollar of increased business. The answer to the question is thus found in the steadily expanding business of the public utility companies, and it is not to be wondered why one of the great bankers of New York, in an address a year ago, estimated that to provide for the new capital requirements alone of the electric light and power companies of the United States an average of $400 000 000 a year would be needed over a long period of years. This new capital, as stated at the beginning of this article, is raised by the sale of bonds or short-time notes, and preferred and common stocks. To raise it all by bonds would be extremely bad financing, so that part of it is secured by the sale of funded securities and a part by the sale of stocks. If any one is fearful that it is not good business to invest $5 of capital to secure $1 of new business we would ask him to do a little figuring. It is probable that it will take 50 or 55 cents out of the dollar of new business to pay for operating expense and taxes. Then if the new capital has been secured on a six percent basis there would be 30 cents to pay for interest, leaving between 15 and 20 cents for surplus. Thus it will be seen that a growing light and power company can invest $5 of capital to finance $1 of new business and still make a good profit on its investment.

Next month we will take up the different classes of bonds and notes, showing just how they rank in investment value and how they may be distinguished. This to be followed by similar articles on the investment values of preferred and common stocks of public utility corporations, with some facts in regard to the more important public utility corporations, the securities of which are being offered to the investing public.

EMPIRE DISTRICT ELECTRIC

Among the bonds which have recently shown good advances in price are the Empire District Electric Company first mortgage five percent bonds, due in 1949. The advance has been due to the large gains in earnings of the company and also to a better knowledge of the bond and the issuing company. There are $3 346 000 of these bonds outstanding, and for 1915 net earnings, applicable to payment of interest on them, were $421,878, or in excess of 2.5 times the requirements. The company is now making the largest earnings in its history, due to the great activity in the lead and zinc mining industry of Southwest Missouri and Southeastern Kansas, a territory which it serves with electric light and power and gas.

WEST PENN POWER

West Penn Power Company, which has just sold $8 500 000 first mortgage five percent bonds to New York and Chicago bankers, is a newly organized corporation which has taken over the electric light and power properties which have been operated by West Penn Traction Company, a subsidiary of American Water Works & Electric Company. The new company is organized under the laws of Pennsylvania, with $10 000 000 common stock, all of which is owned by West Penn Traction Company; $2 000 000 seven percent preferred stock and $8 500 000 first mortgage bonds, issued under a mortgage providing for $50 000 000 authorized indebtedness, with the further issue of bonds being limited by stringent restrictions in regard to cost of property and earnings, and with provisions in regard to maintenance expenditures and depreciation reserves. Proceeds of the first mortgage bonds and of the $2 000 000 preferred stock just sold will be used in retiring all funded and other obligations of the consolidated companies, leaving the property free of all indebtedness other than these bonds and with $2 000 000 cash working capital in its treasury. Territory served by West Penn Power is in excess of 2500 square miles and surrounds Pittsburgh, being a part of that great industrial district. The 75 communities served have a total population of 400 000, with an estimated 400 000 horse-power of available business, the latter being two and a half times the present connected power load of the company.

West Penn Power owns six generating stations of a total capacity of 4811 kilowatts and 987 miles of transmission and distributing system and, in addition, leases the generating station of West Penn Traction at Connellsville with a capacity of 57 000 kilowatts. Under the terms of the mortgage, West Penn Power must construct or acquire prior to January 1, 1921, new power plants having an aggregate of 40 000 kilowatts generating capacity. December 31, 1915, the company had 23 791 light and power customers, with total connected load of 117 300 horse-power. In the last three years the number of customers increased 42.4 percent, connected load 70.5 percent and output of generating stations 94 percent. Earnings of the consolidated companies for the year ended December 31, 1915, were $2 343 056 gross, and $1 138 728 net. As it will require $425 000 to pay the annual interest on the bonds just sold, it will be seen that, after payment of this interest, a balance of $713 728 would be left for depreciation and dividends. Directors of the new company include Samuel Insull, of Commonwealth Edison, Chicago; Guy E. Tripp, of Westinghouse Electric & Mfg. Company; James D. Mortimer, of the North American Company, and H. Hobart Porter, of American Water Works & Electric Company.

GEORGIA RAILWAY & POWER

Georgia Railway & Power Company, which by reason of jitneys in Atlanta and the general business depression in its territory did not make its usual large gain in earnings in 1915, is now coming back to its normal earning ratio. For January, 1916, the first month of its new fiscal year, gross increased $36 212, or 6.46 percent over January, 1915, while net earnings increased $37 094, or 16.2 percent. While operating expenses for the month were reduced $1466, taxes increased $584.

WESTERN STATES GAS & ELECTRIC COMPANY

Western States Gas & Electric Company, a subsidiary of Standard Gas & Electric Company, has just sold $700 000 first and refunding five percent bonds to provide for additional generating and distributing capacity. The replacement value of the property of the company is $7 100 000, and there are $4 687 000 of these bonds outstanding. Net earnings of the company for 1915 were $572 366, with interest charges of $250 000, showing the bond interest well over twice earned.

PERSONALS

Mr. F. W. Scheidenhelm, who has been engaged in consulting hydroelectric practice in Pittsburgh for a number of years, has opened a consulting engineering office in the Equitable building, New York City, in partnership with Mr. D. W. Mead, of Madison, Wis.

Mr. J. S. Pevear has recently been re-elected president of the Birmingham Railway, Light & Power Company and has also been chosen general manager of the company. Mr. Pevear has moved his headquarters from New York to Birmingham to take active charge of operations.

Mr. G. W. Roosa, of the supply sales department of the Westinghouse Electric & Mfg. Company, has resigned to enter the sales department of the Holophane Glass Company, of New York City, where he will have charge of sales in New York, Ohio and Western Pennsylvania.

Mr. R. L. McLelan has accepted a position in the industrial division of the Westinghouse Electric & Mfg. Company and will handle the steam railroad business in Chicago territory. He was connected with H. M. Byllesby & Co., but more recently with Sanderson & Porter, consulting engineers, Chicago, Ill.

Mr. C. R. Dooley has been appointed manager of the new educational department of the Westinghouse Electric & Mfg. Company. Mr. Dooley graduated from Purdue University in 1902 and entered the Westinghouse plant the same year. In 1905 he was assistant manager of the JOURNAL and later was connected with the power engineering department of the Westinghouse Company. In 1906 he was elected president of the Casino Technical Night School and has been interested in educational work ever since.

Mr. William S. Twining has been appointed director of the department of city transit of Philadelphia, to succeed Mr. A. Merritt Taylor.

Mr. P. G. McConnell has resigned his position in the Chicago service department of the Westinghouse Electric & Mfg. Company.

Mr. F. M. Cockrell, who has been in charge of the Chicago publicity division of the Westinghouse Electric & Mfg. Company, has resigned to enter the advertising department of the *Electrical World.*

Mr. E. M. Smith, of the Beardslee Chandelier Mfg. Company, of Chicago, has resigned to become manager of the commercial lighting department and commercial engineer for L. Plaut & Co., 434 East Twenty-third street, New York City. Mr. Smith was formerly connected with the Cleveland office of the Westinghouse Lamp Company.

Mr. G. L. Kothny has terminated his connection with the Westinghouse Machine Company and joined the staff of the C. H. Wheeler Mfg. Company, of Philadelphia, in the capacity of consulting engineer.

Mr. Frank T. Wyman has severed his connection as chief engineer of the Pittsburgh Transformer Company, Pittsburgh, Pa., to accept the position of chief engineer of the Packard Electric Company, of St. Catharines, Ontario. Mr. Wyman is a graduate of the University of Vermont. He spent two years teaching electrical engineering at Drexel Institute, Philadelphia, and two years in the same capacity in the University of Pittsburgh. For the past seven years he has been connected with the Pittsburgh Transformer Company, the last four years as chief engineer.

Mr. P. R. Moody, of the Boston district office of the Westinghouse Electric & Mfg. Company, has resigned to become power solicitor for the Lowell Electric Light Corporation, Lowell, Mass.

Mr. H. W. Clarke, of the department of publicity of the Westinghouse Electric & Mfg. Company, at East Pittsburgh, has been placed in charge of the publicity division of the Chicago district office.

Mr. H. O. Swoboda, consulting engineer, Empire building, Pittsburgh, Pa., has been retained by the Humphrey Company, Kalamazoo, Mich., manufacturers of water heaters, for the purpose of designing a new line of electrical heaters.

Mr. W. T. Scott, formerly in charge of the credit division of the Westinghouse Electric & Mfg. Company's Chicago office, is now with the Hartman Furniture & Carpet Company, 3913 Wentworth avenue, Chicago, Ill., as assistant auditor. Mr. F. A. Ferguson, of the Westinghouse East Pittsburgh credit department, has been appointed to fill the vacancy.

Mr. S. A. Fletcher, of the publicity division of the Westinghouse Electric & Mfg. Company, has resigned to become new business manager of the Birmingham Railway, Light & Power Company, Birmingham, Ala.

Mr. H. E. Drevenstedt, formerly with the Sumpter Lighting Company, of Sumpter, S. C., has been appointed superintendent of the Salem Lighting Company, Salem, O. Mr. Drevenstedt graduated from Yale University, Sheffield Scientific School, in 1913.

Mr. Edward A. Hanff, of the industrial engineering department of the Westinghouse Electric & Mfg. Company, has resigned to accept the position of chief engineer of the Pennsylvania Electrical & Mfg. Company, of Irwin, Pa.

Mr. C. G. Tarkington, formerly a salesman in the Chicago industrial division of the Westinghouse Electric & Mfg. Company, is now with the Snyder Electric Furnace Company, of Chicago.

Mr. George K. Parsons, consulting engineer, has opened an office in the Equitable building, New York City, in addition to his office in the Riggs building, Washington, D. C.

The Standard Underground Cable Company, of Pittsburgh, have just published a descriptive booklet entitled, "Thirty-Three Years of Progress," including a description of their exhibit at the Panama-Pacific International Exposition.

A.I.E.E. NOMINATIONS

The board of directors of the American Institute of Electrical Engineers has selected as its list of directors' nominees for candidates for the Institute offices falling vacant July 31, 1916, the following:—

For president—Mr. Harold W. Buck, of New York.

For vice presidents—Mr. L. T. Robinson, Schenectady, N. Y.; Mr. Peter Junkersfeld, Chicago, Ill.; Mr. B. A. Behrend, Boston, Mass., and Mr. Henry A. Lardner, New York.

For managers—Mr. John B. Fisken, Spokane, Wash.; Mr. Charles Robbins, Pittsburgh, Pa.; Mr. N. A. Carle, Newark, N. J., and Mr. Charles S. Ruffner, St. Louis, Mo.

For treasurer—Mr. George A. Hamilton, Elizabeth, N. J.

THE WESTINGHOUSE CLUB BANQUET

The sixth annual banquet of The Westinghouse Club was held on March 11 at the Fort Pitt Hotel, Pittsburgh. The principal speaker of the evening was Mr. W. L. Saunders, vice-chairman of the Naval Consulting Board, and chairman of the board of directors of the Ingersoll-Rand Company, New York City. Other speakers were Mr. W. G. Carr, patent attorney of the Westinghouse Electric & Mfg. Company, and Rev. Samuel M. Lindsay, of Pittsburgh. Mr. T. P. Gaylord, acting vice president of the Westinghouse Electric & Mfg. Company, acted as toastmaster and was introduced by Mr. G. H. Lewis, president of The Westinghouse Club. There were about 500 present.

NEW BOOKS

"Regulation of Railroads and Public Utilities in Wisconsin" — Fred L. Holmes. 348 pages, 5x8 inches. Published by D. Appleton & Company, New York. Price $2.00.

The ultimate outcome of our present system of utility regulation is a matter of speculation by careful observers of both state and Federal practice. Undeniably public service regulation has its advantages but, if too rigidly enforced or conducted in an academic manner not in harmony with the conomic forces that control the development of utilities, it must inevitably fail. The present order of regulation is comparatively new, and possibly has not proceeded far enough to have evidenced definitely whether its influence upon the industries affected is stimulative or the contrary. In this book the author, who has been active in legislation in the state of Wisconsin, endeavors to portray in an impartial manner the progress made by the Wisconsin Railroad Commission since 1907. Chapters are devoted to provisions of the law on which the commission was organized, valuations, rate of return, standardizing service, accounting, depreciation, rates for different classes of utilities, indeterminate permits, regulation of stocks and bonds, water power legislation, effect of regulation upon investments and the relation of the commissions and the courts. This is the most comprehensive review of the achievement of the Public Service Commission thus far published, and accordingly deserves the careful perusal of those whose interests lie in this direction. E. D. D

NEW BOOKS

"Color and Its Applications"—M. Luckeish. 357 pages, 120 illustrations, four color plates. Published by D. Van Nostrand Company, New York City. Price $3.00.

This book may be considered as being primarily a discussion of the physical basis of color, in that the author has treated the subject of color, even in its relation to art, from the standpoint of pure physics. This is a mode of treatment which has been much needed. We quote from Chapter XIII:—"By no means is it contended that art can be produced by rule of thumb or by scientific formulae. Nevertheless, facts are the basis of all art and, while scientific investigation has not yet revealed all its hidden secrets, scientific explanations can be presented for many supposed mysterious effects." Many of the requirements of color treatment, which are known to painters, but are little understood by most of them, can be explained by the persistency of vision of the eye, its constant shifting and its chromatic aberration and other inherent characteristics which must be taken into account and should be thoroughly understood by the painter who "does not record what he knows to be there, but rather what he sees." The first part of the book gives a discussion of the physical principles underlying the production of light and the production and mixing and analyzing of color. A chapter is devoted to color terminology, which at present is crude and largely unscientific. Several chapters are devoted to the eye, its physiological and physical characteristics and their effect on color vision, as well as the various theories of color vision. Other chapters deal with color photometry; color photography; color in artificial and daylight illumination; color effects for the stage and for display lighting; color phenomena in painting; color matching; the art of mobile color, or color music and its relation to sound music; and a discussion of the various colored media available for experimental purposes. The work is not intended as a complete treatment of the subject, but rather presents to the reader the scientific information which is at present available on this most interesting subject; it should prove of great value to those whose work involves an understanding of the sciences of color. The results of many practical experiments are given. Among these are the relative visibility at different distances of color combinations for advertising purposes; it is interesting to note that black type on a yellow background is the most legible, while black type on a white background (the usual combination) stands sixth on the list of experimental combinations, being surpassed also by green on white, red on white, blue on white and white on blue. Other experiments deal with the effect of different colored light, and especially of monochromatic light both for the acuity of nearby objects and for visibility at a distance. Especially interesting is the discussion of the effect of colored lighting on paintings, tapestry and other color combinations. The viewpoint of practical application has been kept prominently in mind throughout the book. In addition, Dr. Luckeish has presented the information in a most interesting manner. It will occasion no surprise to those who know him by reputation to learn that the entire book is printed on a non-glare paper and from an especially legible type. Bibliographies follow each chapter, with numerous cross-references and an exceptionally complete index. C. R. R.

"Some Things Engineers Should Know Concerning the Rudiments of Corporate Finance"—Ralph D. Mershon. Published by the National Electric Light Association, 29 West Thirty-ninth street, New York City. Price 10 cents per copy.

This address has been published by the National Electric Light Association and deals with the fundamental principles underlying investment of private capital in public utilities and explains the nature of securities issued, such as stocks and bonds. Many public utility employees not directly concerned with the financial department entertain rather vague ideas on the subject. Mr. Mershon's treatment, which is simple, plain and direct, should be of much value and interest to them.

"Elementary Lessons in Electricity and Magnetism"—Sylvanus B. Thompson. 706 pages, 377 illustrations. Published by The Macmillan Company. For sale by The Electric Journal. Price $2.50.

This is the seventh edition of the book originally published in 1894. In the present edition the entire work has been revised and in some parts re-written. A new chapter has been added on wireless telegraphy and another on the modern conception of the electron. The book is arranged with many problems and exercises at the end for classroom work and has been a standard textbook for so long that a detailed review is hardly necessary.

"Ford Methods and Ford Shops"—H. L. Arnold and F. L. Faurote. Size 7x10 inches, 440 pages, illustrated. Published by *The Engineering Magazine*. For sale by The Electric Journal. Price $5.00.

This book is a re-arrangement of a series of articles published in *The Engineering Magazine*, going into elaborate detail as to the methods used in the manufacturing processes in this very interesting establishment. The book is well illustrated with detail photographs of the various production methods. In the present form the book should certainly be of value to all production men interested in machine shop methods, especially those having to do with quantity production. "Safety First" and the latest arrangements for the comfort and convenience of workmen are given considerable attention.

"Electrical Measurements and Meter Testing"—David Penn Moreton. Pocket size, 328 pages, 191 illustrations. Published by Frederick J. Drake & Co. Price $1.00.

This book is prepared especially for those who, having been unable to take a complete course in electrical engineering, are desirous of obtaining a working knowledge as to electrical measurements and testing. Fundamental theories are clearly presented and their practical application shown. Numerous examples and their solution are given, along with illustrations and explanations of various commercial forms of meters, including recording meters.

"Conservation of Water by Storage"—George F. Swain. 369 pages, 91 illustrations. Published by Yale University Press. For sale by The Electric Journal. Price $3.00.

Considering the enormous amount of available water power still unutilized, it is natural to inquire why the development of these great resources is being retarded. Economic reasons would at first seem to satisfy such inquiry, but when we come to see clearly that legislative interference and misconceptions created by self-assumed authorities on conservation have deterred private initiative and capital from embarking upon such enterprises, we realize that such development should be encouraged rather than intimidated. The book comprises a series of lectures presumably intended for classroom work. In any state where available water power is a factor this very lucid and logical resume should be read by its constructive statesmen and progressive citizens. Undoubtedly, engineers are best qualified to lay the foundation for any policy that should be determined upon relative to this far-reaching subject, and this book as a reference will be found of much aid. On the other hand, the non-technical mind should be able to grasp the significant facts that have been presented by the author, and consequently this contribution to our water power literature should produce a positive effect upon the immediate future of this agency. The scope of the book is broader than the mere title would imply. The subjects of forest preservation, floods, navigation, etc., are amply embraced. E.D.D.

"Telegraph Engineering"—Erich Hausmann. 406 pages, 192 illustrations. Published by D. Van Nostrand Company. Price $3.00.

This book is designed for electrical engineering students and as a manual for practicing telegraph and telephone engineers. It presents modern overland and submarine telegraphy from an engineering standpoint. Very little attempt is made to describe particular types of apparatus. The book is based on the course in telegraph engineering given by the author at the Brooklyn Polytechnic Institute. It includes chapters on railway signaling, municipal telegraphs and submarine telegraphy.

NEW BOOKS

"The Telephone and Telephone Exchanges"—J. E. Kingsbury. 558 pages; 170 illustrations. Published by Longmans, Green & Co. For sale by THE ELECTRIC JOURNAL. Price $4.00.

This is an English work which goes at great length into the early history of the telephone industry, with profuse extracts from legal testimony given in various telephone suits. Much of this testimony is interesting, being the verbatim expression of various inventors and engineers as to their understanding as to the various telephone and switchboard developments. The fact that a full-page illustration is given of the inauguration of the New York-San Francisco line January 25, 1915, will indicate that the book has been brought closely up to date The final chapters are devoted to rates and the economics of the telephone.

"Steam Power"—W. E. Dalby. 744 pages, 250 diagrams. Published by Longmans, Green & Co. For sale by THE ELECTRIC JOURNAL. Price $6.00.

This is an extensive treatise on the principles and theory underlying steam power plant practice. The author has presented the subject in a graphic way, and all mathematics and formulae involved have been reduced to as simple form as possible. A unique treatment of the different processes of converting heat and energy in the plant have been introduced in the way of dividing the course of heat energy into three circuits—heating circuit, motive power circuit and cooling circuit. This merely exemplifies the numerous means adopted to explain the facts that should be understood. The steam boiler, steam engine, turbine and condensers are fully covered from a thermodynamic standpoint, and essential considerations in efficient operation are shown. Considerable space is given to the balancing of engines and the laying out of valve motion. The author has evidently given much consideration to American research, as well as to that in England. While the book comprises very valuable text for students, it should prove of use when attempting to reduce the operation of the power plant to a scientific basis. E. D. D.

"Art of Estimating the Cost of Work"—William B. Ferguson. 97 pages, 5x8 inches. Published by *The Engineering Magazine*. For sale by THE ELECTRIC JOURNAL. Price $1.00.

This is a discussion upon the systematic collection and compilation of unit costs for estimating purposes. The data has been compiled by the author in connection with his work as naval constructor, United States Navy, and most of the material given refers to naval practice. Such matters as riveting, chipping, counter-sinking, etc., are gone into quite thoroughly.

"Essentials of Electrical Engineering"—John Fay Wilson. 345 pages; 285 illustrations. Published by the D. Van Nostrand Company, New York City. Price $2.50.

This is a fairly elementary textbook for students on either electrical or non-electrical enginering courses based on the author's classroom experience as instructor of electrical engineering at the University of Michigan. The fundamental laws of the electric circuit are fully developed, after which the study of various machines is taken up, such as generators, motors, transformers, electric lamps, meters, storage batteries and power transmission. Appendixes are included on harmonic quantities, inductance, capitance, complex quantity and resuscitation from electric shock.

"Wireless Telegraphy" — J. Zenneck, translated from German by A. E. Seelig. 443 pages, 469 illustrations. Published by McGraw-Hill Book Company, New York City. Price $4.00.

This work by the professor of physics at the Technical High School of Munich pays most attention to work done in Europe, especially in Germany. The commercial forms of apparatus mentioned are also mostly those of German manufacture. The theoretical phases of the subject are gone into quite thoroughly. Discussions are also given on high-frequency machines for generating equipment. Various forms of receivers, transmitters and antennae are discussed and described, with a concluding section on directive telegraphy.

"Engineering as a Career" F. H. Newell and C. E. Drayer. 226 pages. Published by D. Van Nostrand Company, New York City. Price $1.00.

This book presents suggestions for the guidance of young men considering engineering as a life work from some twenty successful engineers in various lines of activity, such as mechanical engineering, railway engineering, marine engineering, mining, etc.

THE CURB MARKET

FOR SALE

Engine and Generator

One 75 Kw. Crocker-Wheeler 110 Volt Generator, direct connected to Russell Automatic Engine. 265 r.p.m. Steam Separator, Lubricating Device, Switch Board and Instruments. EXCELLENT CONDITION. A BARGAIN!

ZELNICKER
WALTER A. ZELNICKER SUPPLY COMPANY
in St. Louis

Machinery Equipment Tanks

RATES

Positions Vacant, Positions Wanted, Agents and Salesmen Wanted—3 cents a word—minimum, $1.50 an insertion—payable in advance.

For Sale, Wanted and all undisplayed miscellaneous ads—3 cents a word—minimum, $1.50 an insertion. Proposals—$2.00 an inch.

Advertisements in display type costs as follows for single insertions:

1-16 page,	$ 4.00	1 in. single col.,	$ 3.00
1- 8 page,	8.00	4 in. single col.,	10.00
1- 4 page,	16.00	8 in. single col.,	20.00

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FOR SALE

Light Plant for Sale

Instruments, switchboard, exciter, belts, 60 kw. generator, 100 hp. engine, 125 hp. boiler, heater, pump, piping, etc., the complete 60 cycle, 1100 volt electric light plant recently shut down by the Waterford Electric Light Company, Waterford, Pa., on account of purchasing power.

Engine Generator Boiler

One 28" x 56" x 48" cross compound Rice & Sargent engine, direct connected to Westinghouse 1200 K.W., 3 phase, 60 cycle, 2300 v., 90 R.P.M. generator, including Blake Jet Condenser, bronze body. Also twelve Babcock & Wilcox water tube boilers, hp. rating 390; 180 lbs. pressure; including piping, suspensions, Roney Stokers and stoker drive. Boilers may be purchased with or without stokers All apparatus in excellent condition, ready for immediate delivery. Address Narragansett Electric Lighting Co., Providence, R. I.

Engine and Generator

High speed direct connected engine and A.C. generator, 2300 volt, 60 cycle, 3 phase, 400 or 500 kw. Also belted set as above. Address Box 508, Hazard, Kentucky.

Gas Engine

One 14 horsepower Otto stationary gas engine, in first class condition. Sperlich & Uhlig, 18 Piquette Ave., Detroit, Mich.

One 220 Kw., A.C., 60 cycle, 2200 volt, two phase generator, direct connected to 200 r.p.m Buckeye engine, with transformers for supplying 2200 volts, three phase, complete with barometric condenser, motor driven condenser pump, switchboard instruments and instrument transformers. Complete details upon application to Wisconsin Gas & Electric Company, Racine, Wisconsin

Turbo-Generators for Sale

100 Kw. Turbo-Generator units Each unit is a standard high pressure De Laval turbine direct connected to two 50 kw. Moulton generators. These units are in fine condition; will sacrifice for immediate sale; inspection invited. H M. Bruce, Gridley Bldg., Syracuse, N. Y.

Two Corliss Engine Bargains

One 75 hp. Harris Corliss, left hand, wheel 10 ft. x 18 in., 90 revolutions; complete, fine order, ready for service. Price $400.

One 150 hp. Harris Corliss, left hand; wheel 10 ft. x 19 in., revolutions 85. Like new, ready for service Price $650. H. M. Bruce, Gridley Bldg., Syracuse, N. Y.

Surburban Lot For Sale

Live in the country and let the kiddies play in the open. Improved Residence Plot—Oakmont, Penna Lot No. 62, Southwest corner 15th and Oak Streets, 175' x 250'—Price and terms reasonable. Apply to owner, R. J. Dearborn, 70 William St., New York.

HAWKINS *LIBRARY OF* ELECTRICITY

In 6 Leather Pocket Books Price $1 per Volume

Here is a set of books that no man in the ELECTRICAL FIELD should do without. This is the ELECTRICAL AGE in which we live; ELECTRICITY now controls more trades, directs more men, offers more opportunities than any other power that man has yet discovered. Do you wish to know the underlying principles of MODERN ELECTRICAL PRACTICE?

If so, **HAWKINS ELECTRICAL GUIDES** will give you the information. In reality they are a school within themselves, containing a complete study course with QUESTIONS, ANSWERS AND ILLUSTRATIONS, written in plain everyday language so that a practical man can understand the "HOW, WHEN AND WHY" OF ELECTRICITY.

"THAT'S JUST WHAT I NEED"

They are handsomely bound in flexible black leather with gold edges and will readily go in the pocket. THEY ARE NOT ONLY THE BEST, BUT THE CHEAPEST WORKS PUBLISHED ON ELECTRICITY.

Each book is complete in itself and will be supplied $1.00 per copy, but we believe that the complete set is the best bargain.

The books can speak for themselves and a careful examination, page by page, and illustration by illustration, will convince you of their big value.

If you will fill out the following coupon giving all the information requested, WE WILL SUBMIT THE SIX VOLUMES FOR EXAMINATION ON CONDITIONS NAMED

FREE EXAMINATION OFFER

Theo. Audel & Co., 72 5th Ave., New York

Please submit me for examination HAWKINS ELECTRICAL GUIDES (Price $1 each.)

Ship at once, prepaid the 6 numbers; if satisfactory I agree to send you $1 within seven days and to further mail you $1 each month until paid.

Signature ....

Occupation ....

Business Address ....

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FOR SALE

On account of changing to alternating current, we have the following machines for sale; all guaranteed to be in first class condition:—

1—17½ Kw. Type M.P. Form H General Electric, 125 Volt D.C. Generator, compound wound, 1175 R. P. M.—complete with rails and pulley.

1—30 Kw. Westinghouse Type M 125 Volt, 950 r.p.m. D.C. Generator, compound wound—complete with rails and pulley.

1—30 Kw. General Electric, Type M P Form H 125 Volt, 1050 r.p m. D.C. Generator—complete with rails and pulley, and switchboard. Compound wound.

1—50 Kw. Thompson-Ryan 125 Volt, 650 r.p.m. Compound Wound Generator—D.C. complete with rails and pulley.

1—60 Kw. Thompson-Ryan 125 Volt, 600 r.p.m. Compound Wound Generator—D.C. complete with rails and pulley.

1—280 Kw Western Elec. 250 Volt, Compound Wound Generator D.C., 460 r.p.m., 3 bearing heavy base—complete with rails and pulley.

1—30 H.P. 220 V., 615 r.p.m. Western Elec.—shunt wound Motor, Type E-5 AOR, complete with rails, pulley and starting box.

2 30 H.P. 220 V., 675 r.p.m. Western Elec.—Shunt wound motors, Type E-5 AOR, complete with rails, pulley and starting box.

2—10 H.P. General Elec Form B, 1400 r.p m. Motors, Shunt Wound, complete with rails, pulley and starting box.

1—40 H.P. 220 V. Type S Westinghouse Motor, 550 r.p.m.—Shunt wound, complete with rails, pulley and starting box.

1—20 H P. Westinghouse, Type S, 630 r.p.m. Motor Shunt wound—complete with rails, pulley and starting box.

1—30 H P. 2 Ph 60 Cy. Fairbanks-Morse Motor, 220 V., 900 r p m., complete with rails, pulley and starting box.

1—50 H P. 575 r p.m Western Elec., Type E-6 AOR Motor extended shaft on each end. Complete with rails, pulley and starting box.

1—E. P. Allis Horizontal Girder Frame, Right Hand Corliss Engine, 18" x 48", 35" x 16' split fly wheel.

1 —Buffalo Forge Co. 9" x 10" High Speed Engine, Automatic Crank, fly wheel governor, cast iron sub-base.

1—G E. Type M P Class 4-30-100 Form A, 920 r.p m., 115 V. Compound Wound Generator, complete with slide rails, pulley and switchboard.

International Shoe Co.,

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Electrical Machinery Repaired and Commutators Rebuilt Mining and Locomotive Armatures Rewound A. C. Windings

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SECOND FLOOR OTIS ELEVATOR BUILDING

IMPORTANT AUCTION

At Vancouver, B. C., of the Contracting Equipment formerly used by the

B. C. ELECTRIC RAILWAY CO. LTD.

on construction work at Lake Buntzen and Coquitlam Lake. Originally costing $250,000.

Including:—New Baldwin Locomotive and Tender, Air Compressors, Mining Locomotives, Logging and Yarding Engines, Stationary Engines, Hoists, Motors, Pumps, 24 Mechanical Stokers (new), 2 Lidgerwood Panama Type Cableways (complete) 1,100 feet and 1,200 feet span, 2 1-2 inch Cable, Boilers, Drills, Tunnel Bars, 20 tons of Hollow Round and Octagonal Drill Steel, etc.

Will be sold by Public Auction during April. Catalogues on application to the Auctioneers.

F. GRIFFIN & CO.

448 Seymour Street Vancouver, B. C. and *311 California Street San Francisco, Cal.*

THE ELECTRIC JOURNAL

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How to Analyze Costs

One of the difficulties encountered by central station representatives in their efforts to extend the use of electric service among manufacturing concerns is in getting a basis of mutual understanding as to what central station service will cost as compared with the costs actually obtained with some other source of power. A power salesman can usually explain his rates, either directly or in the form of an estimate of total cost, in such a way that the manufacturer receives a definite impression regarding the financial phase of the proposal.

However, when an attempt is made to compare this estimate with the previous costs of operation, it is often found that the power costs have not been given any special attention, except as to such items as fuel, labor, etc. When these items are added and compared with the central station's estimate—a not infrequent procedure—they may give the impression that the purchase of power would not be advisable. Under such circumstances it becomes necessary for the central station organization to make a complete analysis of the situation by securing as accurate data as possible on the various items which properly should be included in any adequate cost determination, including space rental value, repairs, depreciation, interest, taxes, insurance, indirect expenses, supervision, etc. Such an analysis, when properly presented, is not only effective in securing new business, but often is also much appreciated by the manufacturer, as it gives him an insight into the accounting methods of the most progressive concerns. He realizes that an experienced power man has investigated many industries and that his methods are the result of his observations secured both before and after central station service has been introduced.

The central station industry has shown a commendable spirit of co-operation in helping manufacturing concerns to analyze their power problems. But even the working out of the correct method of figuring costs does not solve the entire problem. If the manufacturer once realizes the value of a power cost system, he will naturally wish to apply a similar system to his entire organization. In its fundamentals such a factory cost system is outlined in the present issue of the JOURNAL in an article by Mr. C. B. Auel, entitled "Methods of Figuring Costs." In this article the author takes as a typical example a small machine shop and works out, step by step, in actual figures, the various items entering into manufacturing costs. With such an elementary analysis at hand it should be a comparatively easy matter for any small manufacturer to substitute his own conditions and to determine whether the methods here outlined can be applied effectively to his own problem.

Direct-Current Electrification Standards

We present in this issue in a slightly condensed form the paper read before The Institution of Electrical Engineers, at London, by Mr. N. W. Storer on "The Use of Direct Current for Terminal and Trunk Line Electrification." In this article the whole situation with reference to the possibilities of direct current for heavy traction service is reviewed in detail.

After pointing out the great advantages of the series motor with field control and regenerative braking, the author reviews the advances in direct-current voltages and the complications that were introduced by the necessity for interchangeable operation over systems having different voltages and different locations of contact conductors. The conclusion is inevitable that a certain amount of standardization is advisable in the immediate future. It was recommended especially that standard locations for contact conductors be agreed upon in Great Britain, as has already been done in the United States; further, that 600 volts should continue to be the standard for heavy multiple-unit service for suburban work, and that one other high voltage be determined upon as a tentative standard for trunk line service, which could be decided upon after careful consideration by all parties interested.

The paper presented by Mr. Clarence Renshaw before the American Institute of Electrical Engineers, at New York, April 14th, on the subject, "High-Voltage, Direct-Current Railway Practice," covers somewhat the same ground in this respect. Mr. Renshaw gave some interesting data on the operation of the 5000 volt direct-current car equipment which was described in our October, 1915 issue, and brought the operating records of the equipment up to date. On March 1st this equipment had run over 30 000 miles, and during the four months, November, December, January and February, which on account of weather conditions are ordinarily considered the worst in the year, the car ran 23 320 miles, or an average of 5830 per month. Considering that this was made with a schedule speed of only 15 miles per hour, the result is extremely satisfactory. Neither motors nor high-voltage switch groups have to date shown any defect that can be attributed to the high voltage. On account of the great success of this equipment, Mr. Renshaw suggests 5000 volts as a proper "bogie" for high-voltage, direct-current railways. While, of course, it is too early for the adoption of any voltage as a final standard for direct-current railway electrification, Mr. Renshaw's suggestion is very timely, as it should tend to minimize the number of different voltages with their attendant disadvantages.

Mechanical Considerations in the Design of Railway Motors

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One of the principal conditions to be provided for in designing a railway armature is that the armature shaft can be replaced in case of damage without disturbing the core or the windings located thereon. The easiest way to accomplish this result is to use a cast steel or malleable iron spider as a support for the punchings mounted on the shaft. This construction has given most satisfactory results for many years and is still the most desirable solution of the problem in the case of the larger railway motors with armature diameters of 15 inches and larger. The spider, besides facilitating the removal of the shaft, also has the advantage of considerably stiffening the whole structure. With small diameter railway motors of the ventilated type, especially those motors for small wheel diameters, the space conditions are such that there is hardly room enough for a spider between the punchings and the shaft

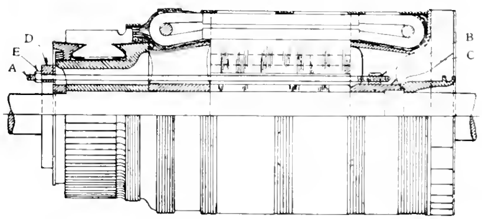

FIG. 1—JIG FOR REMOVING SHAFT OF RAILWAY MOTOR WITHOUT TEARING DOWN THE ARMATURE

after providing for sufficient magnetic core iron under the coils and sufficient ventilating ducts. With such motors it was, therefore, necessary to find means for conveniently replacing the shaft without the use of a spider. One of the early constructions for this purpose is shown in Fig. 1. When replacing a shaft in this case it is necessary to insert the bolts *A* into tapped holes *B* in the casting *C*, and hold the core together by means of these bolts, ring *D* and the nuts *E*, while the shaft is pressed out and pressed in. The ventilating fan and rear wiper ring have been removed to give a solid seat to *D*. The principal difficulty experienced with this construction is that the tapped holes *B* are liable to fill up with dirt and rust during operation, making the insertion of the bolts difficult. A later method with which two rings may be used, together with through bolts *A*, is shown in Fig. 2. The armature core and commutator spider have to be designed in this case with straight holes all the way through. This construction has been in use for a number of years with complete success. Liberally dimensioned shaft diameters inside the core have reduced shaft breakage to a negligible amount, and wherever shaft replacements were necessary they have been accomplished without difficulty.

Properly designed supports for the end extensions of the armature coils are also absolutely necessary in connection with the core design of railway motors. These supports are usually arranged to give mechanical protec-

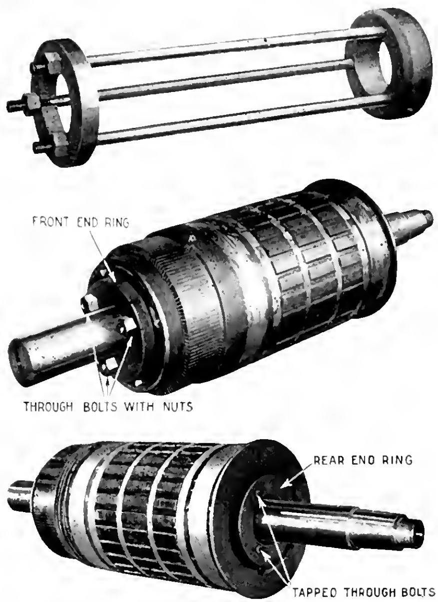

FIG. 2—MORE RECENT JIG FOR SHAFT
Showing jig alone and front and rear views of armature with jig in position.

tion to the coil, besides serving as a support, as shown in Fig. 3.

The construction for holding the punchings on the spider or the shaft must, of course, be such as to avoid their loosening under the very severe vibrations which are encountered in railway service. A certain amount of trouble from loose punchings, which usually results in damage to the armature winding, has been experienced with motors in the past. The up-to-date construc-

tions shown in Figs. 3 and 4, however, have never given any trouble of this kind. The punchings are pressed on and tightened with powerful hydraulic presses and subsequently held in place by a ring nut, which has practically no chance to get loose.

In designing the teeth and slots of the armature core, special attention should be paid to the desirability of having large teeth which will not bend over easily in case the armature rubs against the poles or other sim-

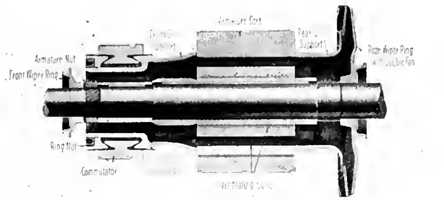

FIG. 3—CROSS SECTION OF TYPICAL RAILWAY ARMATURE
Showing parts as they are mounted on the armature shaft.

ilar conditions which cannot altogether be avoided in railway service. This naturally leads to armatures with rather few large slots and teeth. It is further desirable to avoid any sharp corners along the inner slot surface which are liable to injure the insulation of the coils. The omission of the radial ducts made possible by the recent advent of the fan type motor is, therefore, very desirable.

As a matter of course, it is very desirable to design the armature cores with relatively small diameters in order to keep the peripheral speed low, since high peripheral speeds make it difficult to keep the windings properly secured against movement caused by centrifugal force. A certain amount of trouble caused by loose armature bands and armature coils is known to every railway man, and it is evident that these troubles will be less, the smaller the centrifugal force, which in turn requires a smaller peripheral speed and hence, smaller armature diameter. This particular point is usually not of very great importance with motors up to about 70 horse-power rating at 600 volts. The armature diameters of these motors are usually so small as not to lead to excessive peripheral speeds. With larger motors, however, the subject of peripheral speeds and armature diameter is usually of prime importance and deserves very careful consideration. As in all other matters of design, the choice of armature diameter is a question of compromise; especially in smaller motors, where peripheral speed is usually not excessive, it is not the best practice to choose the armature diameter too small, because by so doing valuable space for ventilating ducts inside the armature core would be lost.

ARMATURE COILS

As previously mentioned, it is usually desirable to design armature cores with rather few large teeth. A small number of teeth means a small number of coils, which is also a desirable feature, because the chances of coil breakdowns to ground are thus reduced. Few and large coils are further desirable, because larger coils are naturally stiffer and less liable to move and bend under service conditions. A stiff coil is especially desirable, because it tends to reduce the movement of the end extensions of the coil which, if present, often lead to the breakage of the coil leads to the commutator. Of course, it is again necessary to compromise, because too large coils are not as favorable for commutation, although it is usually possible with commutating-pole machines to obtain satisfactory results with fairly large coils. It is further to be considered that too large coils may get so stiff as to make the rewinding of the armature difficult. In designing the end connections it is necessary to provide sufficient insulation, but to avoid at the same time unnecessary thickness of insulation between the two layers. The reason for this is that unnecessary insulation increases the chances for shrinkage and consequent movement of the coil extensions which, in turn, may lead to breakage of armature leads.

As previously mentioned, it is essential to avoid any contact of the armature coils with sharp corners of the core, because no matter how well the coil is insulated, its weakest point will always be where it touches a corner. The introduction of reinforcing insulating U-pieces where the coil leaves the armature core has, therefore, been found of very great value in avoiding armature coil breakdowns. All armature coils should, of course, be of uniform shape in order to facilitate winding as well as repairs.

In order to avoid shrinkage of the insulation and consequent looseness of the armature coils in the slots, which often results in chafing and breakdowns of the insulation, it is desirable to have the coil insulation and the wires, in the case of wire-wound coils, compressed as much as possible before the coils are put into the machine. For this reason the practice of hot pressing the straight part of the armature coils is very desirable. The pressing should, of course, be done at such a time and in such a manner as to avoid injury to the insulation during the process of pressing. Coils wound of cotton-covered wire and with a wire covering of fibrous ma-

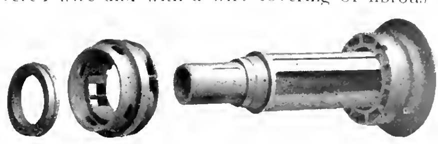

FIG. 4—ARMATURE SPIDER AND RING NUT

terial should be pressed before the outer insulation is put on the coil, while strap-wound coils with mica wrappers may safely be pressed after they are completed, as there is no liability of the flat strap surface injuring the outside insulation during the process of pressing.

ARMATURE BANDING

The banding of the armature should be designed most carefully so as to give maximum strength in the

bands to resist the centrifugal force of the coils, with a large margin of safety. On the other hand, too wide and too many bands are not desirable, because there are certain losses from eddy currents in the bands. The use of a strip of tin under the band wire and clips to hold the band wires together has been found to increase their life and durability considerably. In banding an armature, care should be taken that sufficient fillers are put into the slot to have the coils stick out of the slots at the core portions where the bands are to be located. The amount of the coil sticking out and the pressure used in putting on the bands should be such that after the banding is completed the coil is flush with the top of the teeth and that the band actually rests on the top of the teeth. In order to get the maximum amount of compression of the coil during the course of banding with a minimum amount of subsequent shrinkage of the coil in service, it is very desirable to do the banding while the armature is hot, because the insulating material is most pliable in a hot condition. It will be found that the armature coil may be made to stick out of the slots considerably more when the banding is done hot, assuming that in all cases the banding brings the coil down to be flush with the tooth. From the above considerations it is, of course, evident that hot banding will only be of advantage over cold banding when it is made to accomplish a greater compression of the coil during banding. This means that the hot banding is only good if the coil is made to stick out more above the tooth before the hot banding than is possible with cold banding. The use of temporary bands on the armature before putting on the final bands is also considered good practice.

COMMUTATOR

One of the principal considerations in the design of commutators is, of course, keeping the commutator parts tight in service and avoiding high bars. In the past certain trouble from loose commutator bars has been experienced with the ring nut construction shown in Fig. 5. This trouble was largely eliminated by the intro-

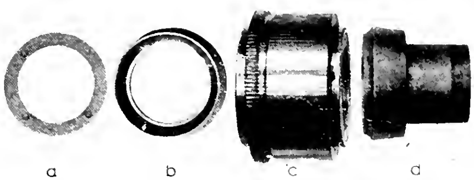

FIG. 5—RAILWAY COMMUTATOR

a—Ring nut. *c*—Complete commutator.
b—Front V ring. *d*—Spider.

duction of the bolted commutator construction, as shown in Fig. 6. With very large commutators, the bolted construction is still the only safe method of holding the commutator together, because the proper tightening of a large ring nut is rather difficult. The methods of manufacturing the mica V-rings and ageing the commutators under heat have, however, improved so much in recent years that the use of a ring nut in small and medium size commutators has become fully as safe as the bolted construction. For this reason, and especially because the ring nut construction permits better ventilation beneath the commutator in connection with fan type motors, the use of the ring nut construction has become quite common again during recent years. A ring nut type of commutator for a ventilated motor is shown in Fig. 5.

One of the most important improvements in commutator design during recent years has been the undercutting of the mica between the bars. It may safely be

FIG. 6—TYPICAL BOLTED COMMUTATOR CONSTRUCTION

FIG. 7—TYPICAL EARLY BRUSHHOLDER
Westinghouse No. 12-A motor.

stated that this feature has done fully as much, if not more, for the perfection of the railway motor than the introduction of the commutating poles. The results are so favorable that even the smallest railway company cannot afford to buy motors without undercut commutators and should arrange for an inspection and maintenance system for keeping the commutators properly undercut at all times. The expense incurred by such maintenance is almost negligible as compared to the saving accomplished in commutator and brush wear. As a matter of fact, it is known that properly undercut commutators in commutating-pole motors have never worn out so that they had to be replaced on that account, and this in spite of the fact that it has been found possible and advisable to reduce the commutator wearing depth of modern motors to about half that of the older motors. Wherever any appreciable amount of commutator wear is noticed in connection with properly undercut commutating-pole motors, it is safe to say that it can always be traced to some unusual cause. Among these may be mentioned the use of improper and abrasive carbons not designed for undercut commutators, excessive brush pressure or the presence of abrasive sands found in some localities.

BRUSHHOLDERS

The design of the brushholder with its inherently small parts so as to stand up under very severe conditions of railway work is one of the most difficult problems in railway motor design. Additional difficulties have been experienced since the use of shunts between the carbon and the brushholder has practically been abandoned in railway work.

One condition to be fulfilled in the design of a brushholder is that a certain fixed and most advantageous

pressure is exerted upon the carbon and that this pressure is kept uniform and in proper direction. The use of a pivoted harness for the pressure hammer has been found advantageous for accomplishing this result, because such a harness causes the hammer to rest in the proper place. A number of brushholders without such harness have been used with more or less success with proper inspection; such brushholders introduce, however, a certain danger that the hammer may rest on the brushholder instead of on the carbon, as shown in Fig. 7.

Another condition to be fulfilled is that the brush should follow small irregularities of the commutator surface quickly, and this can be best accomplished if the masses to be moved up and down with the brushes are kept small. For this reason many brushholder designs include a small vibration spring between the harness and

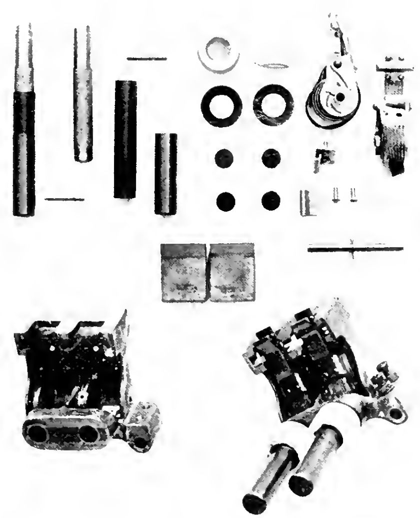

FIG. 8—DETAILS OF TYPICAL MODERN RAILWAY BRUSHHOLDER

the hammer so that the carbon can move without moving the mass of the harness. However, as the mass of the harness is very small in many cases, this refinement is not always necessary. For the above-mentioned reason, i. e., for reducing masses, it is always desirable to keep the weight of the hammer proper as small as possible.

The shape of the hammer has been given much consideration. The shape and size of hammer shown in Fig. 8 has been used for quite a number of years and has given good results in connection with non-commutating pole motors. In commutating-pole motors, however, it was found that, on account of the long life of the carbons, the hammer would wear considerably into the top of the carbon before the carbon was worn out. This results frequently in chipping and breakage of the carbon on top, as shown in Fig. 9. In certain places a smaller and lighter hammer was tried out and found to give better results. While the smaller hammer has less contact surface, it does not wear into the carbon any more than the large hammer and has, moreover, the advantage of less weight and is, therefore, less liable to strike a blow on top of the carbon. It is also quite likely that less breakage was obtained because the distance between the hammer groove and the sides of the carbon is increased and, therefore, the carbon is less liable to break through. In especially severe service, it has been found that a large flat hammer, while not entirely eliminating carbon breakage, will reduce it to a negligible amount. For carbons of small and medium size, a flat or slightly curved narrow hammer extending across the thickness of the carbon has given the most satisfactory results. The very slight wear experienced in this case is of no practical importance, because it does not lead to any carbon breakage on the top of the carbon.

Another difficulty experienced with the brushholder is a certain amount of wear on the sides of the carbons and inside of the brushholder box. With non-commutating pole motors and commutators without undercutting, carbon wear on the commutator surface was so rapid that the side wear of the carbons had no time to develop. With undercut commutating-pole motors, however, the carbons wear so slowly lengthwise that the side

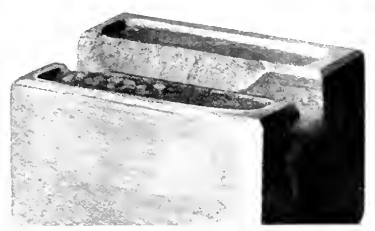

FIG. 9—TYPICAL CARBON WEAR AND BREAKAGE FROM HAMMER POUNDING

wear becomes at times appreciable before the carbon is worn out. Both the hammer wear and the side wear of the carbons is caused by small arcs forming between the carbon and the hammer and between the carbon and the brushholder. Such arcs are formed by the vibration of the carbon inside of the box, and by sand particles getting in between the box and the carbon, conditions which are unavoidable in railway work. The only way to avoid side and top wear entirely is, therefore, to introduce a low resistance shunt between the carbon and the brushholder. However, as shunts are considered impractical by railway operating men, a certain amount of side and top wear cannot be avoided. The amount of wear experienced depends largely upon the vibrations to which the motor is subjected in service, and upon the amount of sand, etc., getting in between the box and the carbon. This in turn depends upon the flexibility of the motor suspension, the speed and condition of the track, etc. It has been found, for instance, that in localities where the cars stop on the near side of the street and where the motors, therefore, carry heavy accelerating current while the car is crossing other tracks,

at a good many places the side wear of the carbons is quite excessive. The vibration of the carbons, and the chances for sand getting in between the box and the carbons, of course depends somewhat upon the clearance between the carbon and the box. With new motors, carefully machined brushholder boxes and proper size of carbons, the side wear can usually be kept reasonably small even under severe service conditions. As any box will wear slightly in time, however, and since most railway companies do not calibrate their carbons so as to make them fit the box closely, the side wear of older motors is often quite noticeable. It is more or less a question of opinion as to whether this is a serious matter. The writer does not know that the side wear found in many localities has ever caused any serious trouble to the motors. It is, however, quite possible that large clearance between the carbons and the box which, of course, exists after a certain amount of side wear, brings about some of the breakage of the carbons, and it is not unlikely that broken particles of the carbon are responsible for some motor flashing by getting between the commutator and the carbons. It might finally be mentioned that the side wear is somewhat affected by the grade of carbon used and possibly by the material of the brushholder. Also, the side wear will, of course, be the larger the less the amount of current carried off by the hammer on top of the carbon and the greater the current which has to pass from the carbon to the brushholder box. For this reason it is very essential that the shunt between the hammer and the brushholder be maintained in first-class condition.

The proper design and good maintenance of the shunt is not only of importance on account of the carbon side wear, but also because bad or broken shunts will also lead to excessive wear of the pins supporting the ratchet wheel and of the inside of the ratchet wheel. It has been found under some conditions with broken shunts that the pin had worn halfway through within a couple of months. Similar damage has been noticed in other cases. All this wear is caused by the current passing from one part to the other and by the small arcs formed between the parts when a separation takes place on account of vibration. If the shunt is carrying the current from the hammer to the brushholder body proper, all such wear is, of course, eliminated or reduced to a negligible amount. Since the material used for the shunt is very liable to break or wear through under vibration, it is essential to design the shunt so that it has the minimum vibration and so that it cannot be chafed through by contact with the edges of the brushholder parts. It is further essential that a shunt should not only be heavy enough, but also that it should form good contact with the brushholder parts at both ends. Since ordinary solder between the hammer and the shunt is liable to melt during severe overloads, special methods of brazing have recently been devised to insure good and permanent contact between the hammer and the shunt.

The brushholder spring should be arranged to give fairly uniform pressure over the wearing distance of the carbon. The choice of material must be such that the spring does not lose its temper with such temperatures as are experienced in railway motors. A flat ribbon steel spring, as shown in Fig. 8, fills this condition best, since it has a bigger section and is much less liable to be damaged during manufacture than a thin wire spring.

It is generally considered advisable to build a brushholder so that the brush tension can be adjusted with the brushholder in the motor, and the ratchet and pawl arrangement, as shown in Fig. 8, has so far been found the best to fill this condition, although some other similar constructions have given satisfactory results. It is quite true that, in most cases, the adjustability of brushholders may be an unnecessary refinement. However, as the most desirable brush pressure depends not only upon the motor design, but also upon the conditions of the road, choice of carbon, etc., it is in many cases quite desirable to be able to readjust the brushholder tension after the motors have been put in service.

The brushholder casting proper should, of course, be of such material and of such design as to avoid breakage under the severe shocks to which it is subjected in service. The use of two insulated pins pressed into the brushholder with porcelain insulators to provide a creepage distance, as shown in Fig. 8, has been found very satisfactory during many years of experience. The pins are arranged radially to the commutator so that, if the brushholder is moved up and down according to the wear of the commutator, the position of the brushholders on the commutator will not be changed.

BRUSHES

Many points regarding the brushes have been touched upon in connection with the discussion of the brushholder and in connection with a previous article on commutation and flashing,* and only a few points need to be added here.

In designing a motor, it is usually desirable not to have the brushes too thin, as they are then more subject to breakage. In most motors a thickness of 5/8 and 3/4 inch, and in small motors of 1/2 inch, gives the best results in actual service. Special attention should be given to the selection of the proper grade of carbon; as a rule, it is not economical to use a cheap grade of carbon, as it can usually be demonstrated by service tests that high-grade carbons are the cheapest in the long run. In selecting between the various high-grade carbons, it is further necessary to select a grade intended for the particular service. Very high graphite and low resistance carbons are often not the best for railway motors. On the other hand, care should be taken to avoid very hard carbons, and especially those with certain abrasive qualities intended for non-undercut commutators. While such carbons may show up very well in comparative tests on carbon wear, they will prove to be expensive on

*See "Commutation and Flashing of Railway Motors," in the JOURNAL for July, 1915, p. 208.

account of excessive commutator wear. In exceptional cases, where a commutator is in bad condition on account of flashing, or possibly because the undercutting is not in good shape, it may be found advisable to use some abrasive brushes for a short while until the commutator is in good condition again. Usually, however, it is better to take out the armature, and turn and undercut the commutators. Under average conditions, the use of medium hard high-grade graphite or carbon brushes with a medium contact resistance gives best results and highest economy in railway motors.

POLE PIECES

The main poles in railway motors are usually built up of laminated iron held together by rivets, while the commutating poles are of rolled or forged steel. Care should be taken to provide both kinds of poles with wide shoulders or recesses for properly holding the coil supporting shields. It is essential that the clearance between the armature and pole pieces be large enough to avoid contact between the armature and the pole pieces with a reasonable amount of wear in the bearings. In order to allow for some wear it is considered good practice to place the armature nearer to the upper pole pieces.

FIELD COILS

The use of flat copper straps in the field coils with asbestos tape insulation between the straps has given such excellent results that the use of wire or ribbon-wound coils has practically been abandoned, except in very small motors, where the copper section is so small as to make the use of strap practically impossible. The insulation between various layers of field coils is usually made of mica discs, which have given good results. In case of field coils for field control motors, special attention has to be given to the insulation between the two parts of the field coils, since it is quite possible to obtain appreciable voltages between the two parts of the field coils on account of the inductive kicks in starting and stopping. Heavy layers of tape are best adapted to protect the field coils on the outside, and impregnating gums or bakelite are used to good advantage for filling up all cavities within the coil, making the absorption of moisture impossible.

One of the most important problems in connection with the field coils is to secure a coil support which effectively avoids vibration of the coil. The best-known means to accomplish this is a heavy spring underneath the coil, together with filling discs for taking up irregularities of castings and coils. No coil, no matter how well it is made, and no matter how exact its seats are cast, can be kept from vibrating without the use of an effective and strong spring, because any known insulation is subject to some shrinkage under heat, which results in changed dimensions of the coils.

Another feature of great interest in the design of field coils is the best method of bringing the cables out of the coil. It has been customary to provide field coils with terminals, into which the cable is fastened by screws. This construction has the advantage that in case of repairs the coils can be easily disconnected, and is entirely satisfactory if the screws are carefully retightened and inspected from time to time. This is, however, a condition which is somewhat hard to fulfill in practice, and it has frequently happened that screws are not properly tightened. This usually results in overheating and consequent burnouts of the field coils near the terminals. Since this is practically the only cause for damage to the field coils and for the necessity of replacing field coils in modern motors, it seems more advisable to use a construction which, while taking a little more time in case of replacement, does not necessitate as many replacements. It seems, therefore, best to permanently attach the cable to the strap inside of the coil with a well-soldered joint and to connect the two cables between the field coils by a similar simple joint of the sleeve type. It takes only a few minutes to open or close such a joint by means of a blow torch, and this little work seems well worth while if it eliminates the troubles which are practically unavoidable with screw and clamp connections. With field coils having the cable ends permanently attached, the simplest type of connection without crossing of cables is usually obtained by the use of two slightly different types of coils, and some care has to be taken that the coils are not mixed up when putting them in the motor. This, however, should give no difficulty if the coils are different in outside appearance or properly marked.

WIRING AROUND FRAME

Special attention should be given to the best way of making the connections between the armature and the various field coils inside of the motor as simple as possible and at the same time properly supporting the cables. Any possibility of vibrations in the cables will lead in time to breakage and consequent burnouts and damage. The cables, therefore, should be properly clamped to the frame or securely fastened to staples forming part of the frame.

Transformer Efficiency and Regulation

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THE transformer losses considered in figuring efficiency are two, viz., iron loss and copper loss. There is a small dielectric hysteresis loss in the insulation which is practically impossible of separate determination. This is kept small by the use of ample distances between points at different potential, and the resultant heating is kept small by a liberal supply of oil ducts through the insulation. It is negligible except in a few rare cases of high-voltage transformers, and the little there is, is included in the iron loss measurement.

IRON LOSS

The iron loss consists of two parts, viz., hysteresis loss and eddy current loss. These two losses can be separated, but there is no reason for doing this in commercial testing, so that the two are included in all iron loss measurements. The iron loss depends upon the frequency and the voltage applied to the windings and is not affected by the load on the transformer except by the small amount that it is reduced, due to the voltage drop through the primary windings. This drop is so small as to be practically negligible to the extent that the iron loss is considered constant for all loads, provided the applied voltage is kept constant. A decrease in the frequency or an increase in the voltage increases the iron loss, and vice versa.

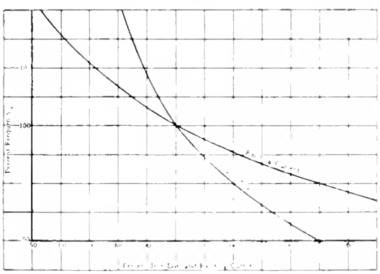

FIG. 1—EFFECT OF CHANGE OF FREQUENCY ON EXCITING CURRENT AND IRON LOSS

The frequencies used chiefly in this country are 25 and 60 cycles. While a transformer can be operated at a higher frequency than that for which it was designed (with poorer regulation on inductive load), it cannot be operated at a much lower frequency without also reducing the voltage, which of course means reducing the rated output. For example, a transformer designed for operation at 60 cycles will generally not operate satisfactorily at normal voltage at 50 cycles. The reason for this is that the iron loss, and particularly the magnetizing current, will be increased beyond reasonable limits, as shown in Fig. 1.

It is customary to design transformers so that they can, when necessary, be operated at a voltage 10 percent in excess of normal. With this increase in voltage, the iron loss will be increased approximately 60 percent and the magnetizing current approximately 100 percent, as shown in Fig. 2. The amount by which the voltage can be raised above normal is limited chiefly by the amount of magnetizing current that is considered reasonable. Ordinarily the magnetizing current of power transformers varies between the wide limits of four or five percent of full-load current for some of the largest sizes to 15 or 20 percent for small high-voltage transformers. For the average size of transformer, the magnetizing current will vary usually between the limits of six and ten percent. An increase of more than ten percent in voltage may raise the magnetizing current to such a high value as to increase the heating of the transformer and appreciably reduce the power-factor of the system.

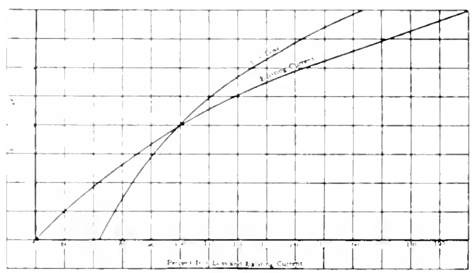

FIG. 2—EFFECT OF CHANGE OF VOLTAGE ON EXCITING CURRENT AND IRON LOSS

The sheet steel used in transformers contains a comparatively high percentage of silicon and is, therefore, popularly known as "high silicon" steel. The loss is very low compared with other kinds of steel, but the permeability is also comparatively low, and this tends to increase the magnetizing current. However, the reduction in loss more than counterbalances the decrease in permeability.

COPPER LOSS

The copper loss varies as the square of the current flowing in the windings. In addition to the useful current that passes to the electrical circuits outside the transformer, there are certain other currents that circulate only in the transformer windings and are not only useless, but are actually harmful, since they increase with increase in load on the transformer and produce

extra heating. They are of two kinds,—eddy currents and circulating currents.

Eddy currents are set up in the individual conductors by the leakage field produced among the windings by the currents flowing in them. They are always present, but can be limited to a small value by careful design. They increase with the width and cross-section of the conductor and are kept within reasonable limits chiefly by winding several comparatively narrow separately insulated conductors in parallel to form one complete conductor. Eddy currents exist to the greatest extent in transformers having heavy, low-voltage, high-reactance windings, that is, transformers for operation with rotary converters.

Circulating currents flow in the loops formed by two or more conductors connected in parallel. They are caused by the leakage field inducing unequal voltages in the different parallel conductors. Like eddy currents they are most liable to cause trouble in heavy, low-voltage, high-reactance windings. They can be eliminated largely by the proper transposition of the conductors when connecting up the coils.

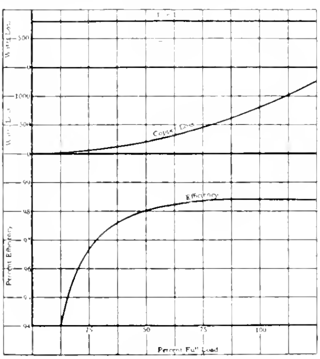

FIG. 3—TYPICAL EFFICIENCY CURVES

The calculated I^2R losses are those losses in the windings caused by the useful currents flowing through them to the electrical circuits to which they are connected. The losses measured by a wattmeter are the I^2R losses plus the losses due to eddy and circulating currents, and are therefore always greater than the calculated I^2R losses. The difference will vary from a very small amount in some cases to as much as 50 percent or more in extreme cases. As a rule, the wattmeter losses do not exceed the I^2R losses by more than approximately 20 percent, except that in high-reactance transformers such as mentioned above, this figure may be doubled.

According to the A.I.E.E. rules, if R_1 = the resistance of the winding at temperature t_1, and R_2 = the resistance at temperature t_2, then $R_2 = \left[\frac{234.5 + t_2}{234.5 + t_1}\right] R_1$. Assuming that efficiency guarantees in one case are made on the basis of a temperature of 25 degrees C., and in the other on the basis of 75 degrees, we have $t_1 = 25$ and $t_2 = 75$; then $R_2 = \left[\frac{234.5 + 75}{234.5 + 25}\right] R_1 = 1.10\, R_1$; i. e., the resistance at 75 degrees is 10 percent greater than at 25 degrees and, therefore, the I^2R loss is also 10 percent greater.

Hence, it is apparent that efficiency guarantees based on wattmeter measurements of copper losses are not as high as those based on calculated I^2R losses. It is also apparent that since I^2R losses increase with increase of temperature, the lower the temperature basis is assumed the higher the efficiency guarantee can be made. For these reasons a fair comparison cannot be made between two different efficiency guarantees unless they are both based on the same temperature and method of measurement. According to the Institute rules, transformer efficiency and regulation guarantees should be based on wattmeter measurements of copper loss, corrected to a temperature of 75 degrees C.

EFFICIENCY

The efficiency of a transformer may be defined as the ratio of the power output at the secondary terminals to the power input at the primary terminals. Since the losses in the transformer make up the difference between the power input and the power output, the efficiency may be stated as

$$Efficiency = \frac{Output}{Output + Losses} = \frac{Input - Losses}{Input}$$

If the iron loss at normal voltage and the copper loss for any given load (generally full load) are known, the efficiencies can easily be calculated, bearing in mind that the iron loss is a constant quantity and that the copper loss varies as the square of the load.

For Example—If a certain 100 k.v.a. transformer has an iron loss of 800 watts and a copper loss at full load of 800 watts, what are the efficiencies at various loads? As the loss varies with the square of the current, at $\frac{1}{4}$ load (25 percent) the loss will be one-sixteenth of full load (6.25 percent), or 50 watts, while at 50 percent load it will be 200 watts; at 75 percent, 450 watts, and at 125 percent, 1250 watts. The efficiency at $\frac{1}{4}$ load will be $E = \frac{Output}{Output + Losses} = \frac{25\,000}{25\,000 + 850} = 0.9671$, or 96.71 percent. The efficiencies at other loads are calculated in the same manner. In making these calculations no account is taken of the magnetizing current which, except in extreme cases, adds such a small amount to the copper loss of the primary winding as to be negligible. The iron and copper losses and efficiency of the above transformer at various loads are shown graphically in Fig. 3.

The efficiency is maximum when the copper loss and the iron loss are equal. Thus, if the copper loss and the iron loss are equal at full load, the efficiency is maximum at full load. If the full-load copper loss is less than the iron loss, the maximum efficiency occurs at some load greater than full load. If the full-load copper loss is greater than the iron loss, the maximum efficiency

occurs at some load less than full load. As a rule, the full-load copper loss as compared with the iron loss is greater for 25 cycle transformers than for 60 cycles.

The above figures are based on the transformer delivering its output at 100 percent power-factor, which is the basis on which all standard performance guarantees are made and is in line with A.I.E.E. rulings. If, however, the guarantees are based on the transformer delivering its output at some power-factor less than 100 percent, then the efficiencies will be less than those shown above.

For Example—Suppose the transformer has to deliver its output of 100 k.v.a. at 80 percent power-factor at normal load and the power-factor remains constant at all loads, what will be the efficiency at the different loads? In this case the currents are the same at the various loads as for 100 percent power-factor, and therefore the losses are the same, but the actual power output is only 80 percent as great. Considering the one-quarter load efficiency, we have then $E = \frac{Output}{Output + Losses} = \frac{0.8 \times 25000}{(0.8 \times 25000) + 850} = 0.9592$, or 95.92 percent; whereas the efficiency at 100 percent power-factor was 96.71 percent.

REGULATION

In general terms the regulation is the variation in secondary voltage with variation of load and power-factor. The greater the load and the lower the power-factor, the greater is the drop in voltage as the load is increased. The voltage drop varies directly as the load, provided the power-factor remains constant. A leading power-factor tends to raise the voltage, and a lagging power-factor to lower it. On non-inductive load (i. e., with a load of 100 percent power-factor) the regulation, as a rule, exceeds the copper drop by only a small amount. However, with transformers having high reactance this is not the case, since the reactive component of voltage adds considerably to the copper drop. On inductive load the regulation depends chiefly upon the reactive drop; hence, the less the reactive drop, the better the regulation, and vice versa. Particularly good regulation on inductive load is not of much importance except for distributing transformers.

A formula commonly used for calculating regulation is

$$\text{Percent Regulation} = IR \cos\theta + IX \sin\theta + \frac{(IX\cos\theta - IR\sin\theta)^2}{200}$$

in which θ = the angle of lag of current behind the voltage,

IR = the percent drop in phase with the current,

IX = the percent drop in quadrature with the current.

For convenience in calculating regulation, the values of $\cos\theta$ and $\sin\theta$ for loads of several different power-factors are given in Table I. $\cos\theta$ is the power-factor and $\sin\theta$ is the reactive factor of the load.

TABLE I

Percent Power-Factor	cos θ	sin θ	Percent Power-Factor	cos θ	sin θ
100	1 00	0 000	75	0 75	0 661
95	0 95	0 312	70	0.70	0 714
90	0 90	0 436	65	0 65	0 760
85	0 85	0 527	60	0 60	0 800
80	0 80	0 600	55	0.55	0 835

For a load of 100 percent power-factor $\cos\theta = 1$ and $\sin\theta = 0$, so that the formula for regulation becomes

$$\text{Percent Regulation at 100 percent power-factor} = IR + \frac{(IX)^2}{200}$$

The values of IR and IX are obtained as follows:—Short-circuit one winding of the transformer and apply to the other winding a voltage of correct frequency and of such a value as will cause full-load current to flow in the windings. By means of a voltmeter and wattmeter measure the volts and the watts input to the transformer under this condition. The volts expressed as a percent of the normal voltage of the winding on which they are measured give the impedance drop IZ, and the watts expressed as a percent of the rated output of the transformer give the IR drop. Knowing the impedance drop, IZ, and the IR drop, the reactance drop, IX, can be calculated from the formula,—

$$IX = \sqrt{(IZ)^2 - (IR)^2}$$

Low reactance may influence the design adversely in the way of cost and efficiency, and when dealing with the larger sizes of transformers, particularly those of low frequency, may make the short circuit stresses so high that it will be very difficult, or possibly out of the question, to brace against them successfully. On the other hand, with a carefully worked out design, there is no good reason for a very high reactance. High reactance generally tends towards a cheaper design, but the resulting poor regulation will in most cases more than offset the possible small saving in cost. As a rule, the tendency is for the reactance to increase with increase in size, voltage and frequency.

Transformers for the operation of compound-wound rotary converters, particularly those for railway work, are as a rule designed for an internal reactance of approximately 15 percent. This is done for the reason that the high reactance tends to cause the direct-current voltage to rise as the load increases.

The Engineering Evolution of Electrical Apparatus—XXII

THE HISTORY OF THE LIGHTNING ARRESTER—*(Cont.)*

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EXPERIMENTAL work on the non-arcing metal lightning arrester being finished, the next step was to place it on the market. This proved to be no easy matter. Operating managers were skeptical; and indeed they were justified in looking askance at a lightning arrester which proposed to interrupt a 1000 volt alternating-current short-circuit by virtue of some mysterious property in a few brass cylinders placed 1/32 inch apart. So persistent, in fact, was this skepticism that the writer found it necessary to make a demonstration trip. Seven non-arcing metal cylinders, each one inch long and three-fourths inch in diameter, were mounted on a strip of wood provided with terminal binding posts. With this and a roll of tin foil in his grip he interviewed the managers of the principal operating plants from New England as far west as Denver and explained the properties of the non-arcing metal lightning arrester. In most cases a good deal of interest was manifested and permission was granted to make a short-circuit test in the power house, but this was not always the case. In some instances the whole proposition was treated as a fake or the product of an unbalanced mind.

The short-circuit test in the power houses was always an interesting experience. As a matter of convenience and saving of time no short-circuiting switch was used; and incidentally this procedure made the test all the more impressive. The strip of wood on which the seven cylinders were mounted was placed on the floor near the dynamo to be short-circuited. One binding post from the cylinders was connected to one terminal of the dynamo, and then holding in the hand a stout insulated wire, one end of which was connected to the other terminal of the dynamo, the short-circuit was completed by touching the other terminal of the cylinders with the end of the loose wire, the air-gaps having previously been short-circuited with crumbs of tin foil. In every case the first test was looked upon as the act of a crazy man. Those who had assembled to witness the test saw it from nearby doors and windows and watched from a distance what to them was the inevitable destruction of something, they probably didn't know exactly what. After the first performance and a careful examination by all of the uninjured metal cylinders there was generally a request for repetitions of the test. These were followed by undisguished astonishment, particularly as, in almost every set of these tests, one or two instances would show that not all of the crumbs of tin foil had been melted. In this manner conviction was carried to the principal central stations, and the eye-witnesses to the experiments spread the information to others, so that it was not long before this type of lightning arrester was generally adopted wherever alternating-current light and power service was used.*

In the meantime interesting things had been happening in connection with the already described explosive air blast types of lightning arresters. Complaints of lack of protection were insistent and became more and more numerous, so that a thorough investigation became necessary. This investigation changed the then prevailing idea that a lightning arrester must necessarily be defective if it failed to protect the apparatus, and was largely instrumental in leading to improved methods of generator insulation. There were three prominent things which this investigation disclosed:—

First—That lightning arresters were in most cases carelessly and ignorantly installed. Sometimes an excessive length of ground wire was formed into a coil to take up the slack. Ground connections were almost invariably defective from one cause or another. In one of the many instances which came under the writer's observation a $1000 equipment of lightning arresters was grounded by simply wrapping the bare ground wire loosely around an iron spike about two feet long and driving this into a sand bed. In another instance the ground plate was buried in clay. In another case the ground plate of a large bank of lightning arresters in a railway power house had been fastened to a ground wire and then thrown from a bridge into a good-sized stream of water. This was done in the early spring when the water was high. When this inspection trip was made the ground plate was found dangling from the bridge at the end of the ground wire and swinging in the air quite free from the water. And so a great variety of defective ground connections was discovered.

Second—It was found that in many instances the electrical equipment was abused and overloaded to such

*The discovery of the non-arcing metals was announced at the sixty-fifth meeting of the American Institute of Electrical Engineers on March 15, 1892, and later this discovery and the design of the non-arcing metal arresters were acknowledged by the Franklin Institute in the award of the John Scott medal.

an extent as to deteriorate the insulating material rapidly. In one instance the writer noticed an electric car hauling five loaded trailers home from a ball game. He subsequently visited the power house and there found a large pile of discarded armature coils, the insulation of which was so charred that it easily crumbled in the hands and fell from the wire. It was also found that armatures were roughly handled in the repair shops to the disadvantage of the insulating material. In this manner it was learned that, although street railway plants might be provided with lightning arresters, it was unreasonable to expect protection unless the insulating material was intact and of sufficient strength to offer a much higher resistance to the passage of lightning discharges than did the spark gap of the lightning arrester.

Third—Having discovered these abuses of insulating material in service, attention was next directed to the handling of the insulating material in the factory, and there it was found that pencil marks were freely used on the insulating material, thereby offering opportunities for surface discharge, and armature coils were beaten and hammered into their respective slots by piece-workers to the great disadvantage of the insulation of the armature. These findings were reported to the management, with the statement that it was hopeless to expect protection from lightning arresters unless these abuses in the factory were removed and the insulating material known by actual test to be intact.

Thus the three important advantages gained by this investigation were,—a better understanding on the part of operators as to the requirements of installation with especial reference to ground connections; a better understanding on the part of the operators as to the care and maintenance of their armatures with reference to the insulating material, and a disclosure that insulating material was abused in the factory and that lightning arresters could not be expected to protect defective apparatus. From this time on great improvements were made, not only in the art of applying insulating material, but also in its quality as well.

About this time a Toepler-Holz electrostatic machine was procured and many experiments were performed seeking information as to the behavior of disruptive discharges on charged wires and the value of choke coils as an additional protection to be used in connection with lightning arresters.* It happened at this time also that Mr. C. E. Skinner was experimenting on a method of increasing the striking distance of a given e.m.f., and many experiments were carried out along these lines in the endeavor to construct an easier spark gap for a lightning arrester than the air-gap, and while nothing definite was accomplished, still the experiments themselves led from one thing to another until a form of lightning arrester was designed for direct-current circuits which had no moving parts and was, strictly speaking, non-arcing in that it allowed the disruptive discharges to pass, but did not allow the dynamo current to follow. In other words, there was no arc rupturing feature.

It is not clearly remembered just what led to the conception of the first form of this type of lightning arrester, but it had long been recognized that lightning arresters of the explosive, air-blast type having moving parts were not ideal and left much to be desired, and the success of the non-arcing metal lightning arrester for alternating-current circuits made it increasingly desirable that an equally effective and simple lightning arrester be constructed for direct-current circuits. The initial thought along these lines seems to have been to construct a spark gap, having terminals so protected that vapors could not be formed from them, for it was reasoned that if the metallic vapors which are necessary for the formation of an arc could be suppressed, then the usual short-circuiting arc could not be formed. The first experiment made along these lines was as follows:—Two perfectly flat strips of marble with ground surfaces about six inches long, one inch wide and one-half inch thick were procured and securely fastened together with two aluminum foil terminals placed between the marble surfaces, about three-fourths inch apart and with pencil marks made on one marble surface between the opposing aluminum foil terminals. The terminals were then connected to the static machine and a battery of Leyden jars; also to a 500 volt direct-current railway generator. It was found that the disruptive discharges readily passed from one aluminum foil terminal to the other between the marble surfaces and over the pencil

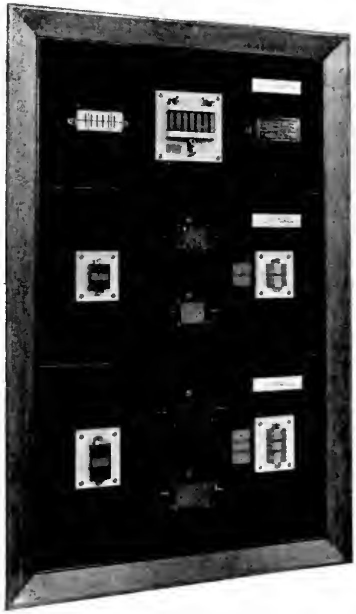

FIG. 12—TYPICAL LIGHTNING ARRESTERS
Top panel—Alternating-current lightning arrester.
Middle panel—Railway lightning arrester.
Bottom panel—Arc circuit lightning arrester.

*Some of these experiments are recorded in the *Journal of the Franklin Institute* for June, 1895.

marks without allowing the dynamo current to follow. In other words, static discharges could pass, but dynamo current could not. The spark gap terminals had been so covered up that there was no space for metallic vapors and the usual short-circuiting arc, as in a lightning arrester, could not form.

Other experiments were then performed along the same line in the endeavor to test out thoroughly the possibilities of such a device as a lightning arrester. The distance between the terminals was decreased to one-half inch with a considerable factor of safety, and when an ordinary spark-gap lightning arrester was connected in parallel with this device it was found that the disruptive discharges found an easier path over the one-half inch pencil surface than through the air-gap lightning arrester.

So far the tests seemed to promise a thoroughly simple, inexpensive and non-arcing type of lightning arrester for direct-current service, and steps were taken to design a commercial lightning arrester along these lines. This took the form of a solid block of marble about six inches long and two inches square having a three-fourths inch hole bored lengthwise from end to end. In the center of this hole there was placed a wooden plug having longitudinally burned grooves; the latter were to take the place of the pencil marks used in the experiments. Round brass terminals were then cemented into the marble holes on either side of the wooden plug and extending beyond the marble on either side. These marble blocks with their brass terminals were suitably mounted on a base for central station use or in iron boxes for outdoor use. But before they were offered for sale it was decided to construct a considerable number and send them to Colorado Springs to be tried there on the street railway system of that city, as this city had a reputation for frequent and violent thunder storms.

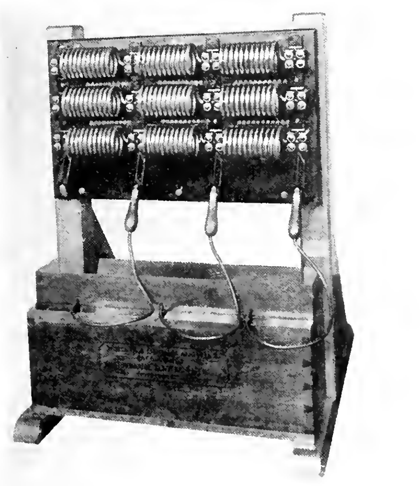

FIG. 13—WURTS TANK LIGHTNING ARRESTER FOR 1000 AMPERE DIRECT-CURRENT RAILWAY CIRCUIT

The water inlet is connected to the city mains, forming the best possible ground connection.

This test was carried out, and it was well this was done, because this particular form of the lightning arrester proved defective in that it failed to recognize the fact that disruptive discharges from the line required space when passing through the lightning arrester, that is, more space than was provided for by the charred grooves made in the wooden cylinders, the result being that one after another of these lightning arresters was completely shattered by the expansive force of the disruptive discharge. However, the experiment was well worth the cost, for not only had it avoided sending out an untried and defective lightning arrester, but it proved beyond question that these lightning arresters had conducted disruptive charges to earth, thereby protecting the apparatus.

It remained now to construct a lightning arrester, observing the same principles for suppressing the arc of short-circuit, but providing an adequate vent for the expansive force of the disruptive discharge. This was accomplished in the following manner:—Two flat brass strips were inserted into a block of lignum vitae wood so that they were flush with the surface of the wood and one-half inch apart, as shown in the middle panel of Fig. 12. The one-half inch space was grooved with a burning iron to provide the discharge surface, as in the marble type of arrester, and the block was then covered with a second block of wood having a transverse slot cut in it in such a manner that when the disruptive discharge passed, the spark and displaced air would have a vent on either side through the slot.

This lightning arrester was made in several forms, as shown in Fig. 12. In one form the wooden block was mounted on a marble base for station use, and in another it was mounted in an iron box for line service. Also on the bottom panel will be seen the same form of lightning arrester, but with two spark gaps in series, mounted both for station and line service. The latter form, with two gaps in series, was designed for voltages higher than 500 volts and primarily for arc light service.

Again it was deemed wise to test these lightning arresters for a season in Colorado before they were offered for sale. They were installed on the lines of the Colorado Springs Street Railway Company and of the Cripple Creek Railway Company, and as these instruments were strictly non-arcing and gave no evidence of the passage of discharges unless an observer were on watch at the time, it was decided to place a small air-gap in a separate iron box and in series with each one of these arresters and then insert a bit of tissue paper in these air-gaps to serve as a "telltale" of the disruptive discharges. These papers were then collected after each thunder storm and a record kept of the performance of the lightning arresters.* A large number of these tell-

*Some of the telltale papers perforated with lightning discharges are shown on page 15 of the *Franklin Institute Journal* for June, 1895. The papers are reproduced in actual size and clearly indicate the passage of disruptive discharges without dynamo current following

tale papers were collected, no lightning arresters were destroyed and the electrical apparatus was protected. In fact, with these arresters the operating companies learned that they could operate through thunder storms with comparative freedom from damage, whereas in the past their custom had been to open their switches and pull down their trolleys until the storm had passed.

During this same summer, 1894, a considerable number of these lightning arresters were connected on the lines of the McKeesport & Wilmerding Railway, fourteen miles southeast of Pittsburgh, for the purpose of determining, even if only approximately, the number of lightning arresters which should be connected to a circuit for a reasonable amount of protection.† While it cannot be said that these experiments led to anything definite they, nevertheless, clearly indicated that dependence could not be placed upon a single lightning arrester in the station, or even upon the few additional ones installed on the cars, for in this experiment the telltale papers indicated that the discharges occurred indiscriminately among the lightning arresters scattered over the line—the inference being that had these line arresters not been installed the electrical apparatus would certainly have been subjected to greater strains and greater danger of disruption.

While these experiments were going on another form of lightning arrester had been designed and was being tried out in service, particularly in street railway power houses. It was called the "tank" lightning arrester. Experiments had shown that lightning discharges did not pass through any one particular lightning arrester; in other words, that they had a tendency to "side flash" from the line without any apparent regard for the so-called shortest and easiest path. The aim of the tank arrester was to provide a multiplicity of discharge paths along a considerable length of wire by coiling up a portion of the wire and placing it in a tank of well-grounded water. It was thought that the surges which occur during thunder storms would in passing through such a coil tend to "side flash" from one or more points through the water and thence to earth; furthermore, it was thought that the resistance offered by the coil would increase this tendency; and finally it was thought that a semi-ground of this kind would provide a leakage path for the electric charge and thereby probably reduce the danger.

There was considerable experimentation along this line.‡ However, owing to the fact that the coil disintegrated rapidly under electrolytic action and that there was continuous leakage whether a thunder storm were in action or not, the tank lightning arrester finally took the form shown in Fig. 13. The lower part consists of a wooden tank with a metal lining, and above there is a set of choke coils connected in multiple-series with a trolley or feeder, as the case might be. Connection is then made from three points on the set of coils to corresponding flat carbon electrodes within the tank. Running water was used, this being found materially to reduce the current leakage which, with a one-half inch water pipe and ordinary city pressure, was from six to seven amperes at 500 volts.

(To be continued)

†These experiments are described in detail in *Electric Power* for February, 1895, under the heading "Notes on Protection Against Lightning Collected During the Summer of 1894."

‡See the A.I.E.E. paper of March, 1892, previously referred to

Short-Circuit Current of Alternators

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When an alternator is short-circuited the current rises during the first cycle to a maximum value, and then rapidly decreases to a constant value, known as the "sustained short-circuit current." Generally speaking, this transient rush of current is due to the fact that the armature synchronous impedance cannot rise instantly to its normal value, because time is required for the armature reaction to take its effect on the field.

Synchronous impedance* combines the effect of inherent or leakage reactance and armature demagnetization. The armature current tends to demagnetize the main field. The main field, however, represents a definite amount of stored energy which cannot be demagnetized instantly, but only at a rate depending on the effective resistance and self-induction of the paths through which it may discharge. Thus at the instant of short-circuit the effective synchronous impedance consists only of the inherent reactance and, as time progresses and demagnetization becomes effective, the synchronous impedance increases rapidly and reaches its normal value when the armature current reaches its sustained value.

The current in at least two of the phases of a three-phase machine will always be unsymmetrical at the instant of short-circuit. The period for which this dissymmetry exists depends upon the electrical characteristics of the windings. On most machines the waves become practically symmetrical in from 0.15 to 0.25 second.

The dissymmetry of the phase currents is usually explained mathematically. It is possible, however, to obtain a physical conception of this phenomenon by the application of the fundamental rules governing flux, voltage and current. The phase winding which is located midway between the field poles at the instant of

*See article on "Generator Short-Circuit Current Waves," by Mr. F. D. Newbury, in the Journal for April, 1914, p. 196; also Question Box Nos. 1109 and 1129; and Engineering Notes, "Synchronous Impedance," in the Journal for February, 1915.

short-circuit will have a maximum of unsymmetrical current induced in it, because it is situated so as to receive the fullest effect by transformer action of the rapidly decreasing field flux. The field flux, under the variable demagnetizing action of the unsymmetrical armature current, undergoes a cyclical variation in magnitude (as may be seen from oscillograms of field currents), so that all phases successively passing the poles do not have the same unsymmetrical current (voltage) induced in them. The phase winding situated at the center of the pole at the instant of short-circuit is on the magnetic axis as far as this cyclical oscillation of field flux is concerned, so that it has no unsymmetrical current induced in it. The unsymmetrical currents are not due to any flux distortion in the air-gap, but are rather the effect of the field flux discharging through the armature circuit. The sum of the maximum values of current in the first two alternations is nearly the same for all phases.

The effective resistance of the field circuit changes considerably while the field is being demagnetized. The eddy current and other losses incidental to the rapidly changing flux and large currents produce a watt loss which is equivalent to an increased variable resistance, which cannot be measured under normal open-circuit conditions.

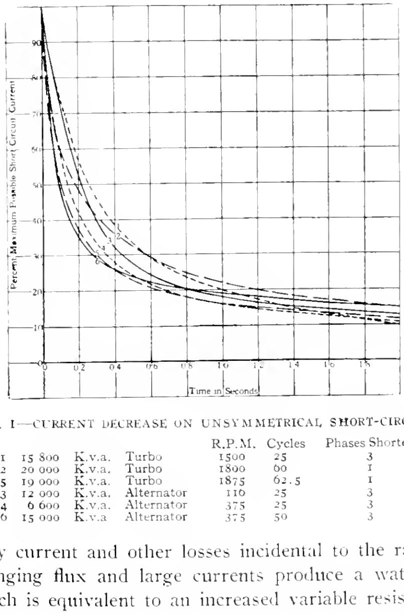

FIG. I—CURRENT DECREASE ON UNSYMMETRICAL SHORT-CIRCUITS

				R.P.M.	Cycles	Phases Shorted
1	15 800	K.v.a.	Turbo	1500	25	3
2	20 000	K.v.a.	Turbo	1800	60	1
5	19 000	K.v.a.	Turbo	1875	62.5	1
3	12 000	K.v.a.	Alternator	110	25	3
4	6 600	K.v.a.	Alternator	375	25	3
6	15 000	K.v.a	Alternator	375	50	3

A resume of a number of tests on various types of alternators showed that the transient component of the short-circuit current did not follow any simple logarithmic law as might have been expected, probably as a result of the change in the effective resistance in the field circuit. Single-phase short-circuits showed a considerably faster rate of decrease of current than polyphase short-circuits in the same machine. For equal currents per terminal the polyphase short-circuit has roughly 50 percent greater demagnetizing ampere-turns than the single-phase, so that the faster rate of decrease with the single-phase condition would indicate sufficiently high additional losses (or the equivalent of high resistance) such as usually accompany single-phase armature reactance, to offset the greater demagnetizing strength of the three-phase armature reaction.

The effect of a damper winding on the rate of decrease, due to its ability to prevent rapid change of field flux, is not apparent from tests. If the main field does not change so rapidly when encircled by a damper, then the current induced in the armature by the transformer effect of the decreasing main field is lessened, while the e.m.f. due to rotation is maintained, so that the total effect on the magnitude and rate of decrease of current is little, if any.

Considering the widely different electrical and mechanical characteristics of the prevailing types of alternators (slow-speed engine type, water-wheel and high-speed turbo-generators), it would scarcely be expected that any one simple rule for the rate of decrease of current after short-circuit would apply equally well for all classes of machines for both 25 and 60 cycles. Comparing different oscillograph tests on the same machine, it is very seldom that the same degree of dissymmetry has been duplicated in any two tests. In order to form a basis of comparison, it was necessary to compare all machines either on the basis of symmetrical short-circuits, or on the other extreme basis of totally unsymmetrical short-circuits. By a totally unsymmetrical short-circuit is meant one in which the first current cycle takes place above the zero line. This latter basis was adopted, as it apparently represents the most severe conditions on the machine and its auxiliary circuits.

The rate of decrease of maximum possible instantaneous current on a totally unsymmetrically short-circuit is shown in Fig. 1 for a few typical machines, of the salient pole alternator and distributed field winding turbo-generator type, for both 25 and 60 cycles. These curves include single-phase and polyphase short-circuits on machines with and without damper windings. Many more tests could be shown that fall within the limits shown on the curve.

It is not commercial practice to take oscillograms covering a period of time greater than from one-quarter to one-half second, except in special cases. A considerable portion of the data available consisted of short-time tests, and in such cases it was necessary to determine the equation of the curve of current decrease and to extrapolate it. The diversion of the transient component of current from any simple logarithmic law was very marked in all of these curves, especially during the first quarter of a second. The test conditions under which this data was obtained differ from the conditions found on commercial circuits, in that the machines tested were not equipped with automatic voltage regulators. The effect of a regulator is to increase the sustained short-circuit current to several times the value shown, without making any appreciable difference in the rate of decrease of current during the first few seconds.

The Use of Direct Current for Terminal and Trunk Line Electrification*

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THIS ARTICLE deals chiefly with the characteristics and possibilities of the direct-current motors for handling trains in the most economical and satisfactory manner, not only on one line, but for interchanging equipments on lines where different conditions prevail.

IT IS only about thirty years since the electric motor was first used in real commercial railway service. Many experiments were made prior to that time, but the railway motor did not become commercial until the first series-wound motor was geared directly to the car axle. Electric railroading then progressed by leaps and bounds. The invention of the multiple-unit control system gave a great impetus to its growth, and now electric motors have been applied to practically all classes of railway service.

A great many changes have been made in the direct-current motor in the last twenty-five years. As might have been expected, the requirements of a motor for railway service were, at first, but little understood. The insulation was poor, the mechanical design was worse, and the commutation bad. However, improvement has been rapid and continuous, until the up-to-date direct-current, commutating-pole, self-ventilated and oil-lubricated railway motor leaves little to be desired, either electrically or mechanically. While the design of the motor has been perfected, the principles that led to the selection of the series motor are the same as they were when the advantages of its steep speed and torque curves were first seen. Now the direct-current series motor is used almost universally for street and interurban railways, underground and elevated lines, and very largely for the electrification of the terminal and suburban lines of steam railways. The steep speed curve makes the series motor more nearly fool-proof and, therefore, more reliable and cheaper to maintain than any other direct-current type. It introduces a degree of elasticity that enables the motor to withstand the severe service of rapidly accelerating heavy trains and developing overload torques that would be impossible in any other type. It also gives the best commutation and is least subject to injury resulting from the fluctuating line voltages that are common to all electric railways.

SERIES MOTOR CHARACTERISTICS

The series motor as generally used has not the most efficient characteristics. It is the series motor in its simplest form that is now used most extensively. As a rule the field becomes saturated at a current corresponding to about the one-hour rating. This is the result of the effort on the part of the designers to secure the maximum output on one-hour rating with the minimum weight of material. In Fig. 1 are shown corresponding speed and torque curves for two motors—one with saturated and the other with unsaturated magnetic circuits. The speed curves cross at approximately 42 m.p.h. (miles per hour), but at the one-hour rating of the motor, which is practically 350 amperes, the speed of the saturated motor is 37 m.p.h., while the other runs at 33 m.p.h. While one motor requires 350 amperes to develop 2500 lbs. tractive effort, the other one requires only 320 amperes. For frequent stopping service the unsaturated motor will operate more efficiently, since it accelerates with less current. In such service also the root mean

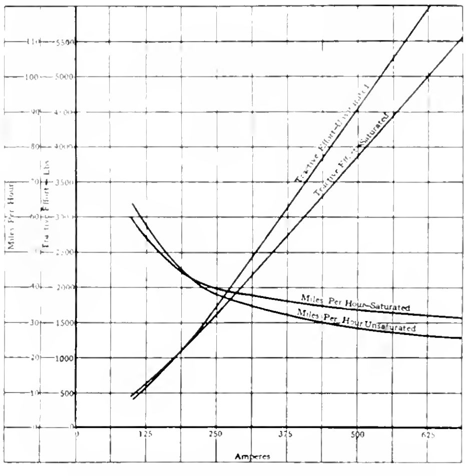

FIG. 1—COMPARATIVE CURVES FOR 250 HORSE-POWER, 600 VOLT, SATURATED AND UNSATURATED MOTORS

square current in a given class of service will be materially less in the unsaturated motor; consequently, an unsaturated motor of a given rating will have a greater service capacity than the saturated motor. If this point were thoroughly borne in mind, the manufacturer of the unsaturated motor would not be penalized on account of the small rating of an unsaturated motor of a given weight, or on account of greater weight with a given rating and the railway company could operate with higher efficiency. These points are brought out in Fig. 2, which shows that the rheostatic losses vary directly as the square of the speed at which the last resistance is cut out of the motor circuit, or at which the motor curve

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at full voltage is reached. For instance, if the load were accelerated at a tractive effort of 3300 lbs., Fig. 1, the speed curve on the saturated motor would be reached at a speed of 35 m.p.h., while the unsaturated motor would reach the speed curve with the same tractive effort with about ten percent less current and at a speed of 31.5

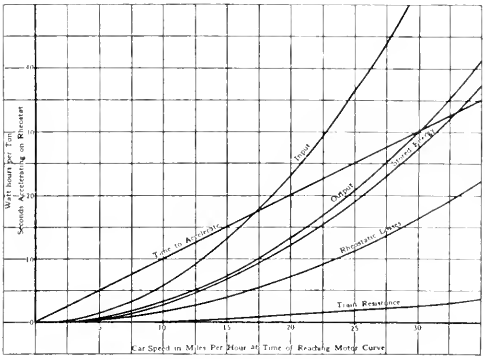

FIG. 2—ANALYSIS OF POWER CONSUMPTION IN STRAIGHT LINE ACCELERATION

Data:—Weight	1 ton (2240 lb.)
Acceleration	1 m.p.h. per sec.
Total Tractive Effort	121 lb.
Train Resistance	11 lb.
Allowance for Rotating Inertia	7.5 percent
Control	Series-Parallel
Motor Efficiency at Normal Voltage	.88 Percent
Voltage Drop in Motor	5 Percent

m.p.h. The rheostatic losses from Fig. 2 would be 22.2 watthours per ton in the one case, and 18 watthours per ton in the other, a saving of 4.2 watthours per ton for each acceleration. Of course, a motor geared for such high speed as this would not make more than one or one and one-quarter stops per mile, but in any case there would be a certain definite saving for every acceleration that the motors are required to make.

FIELD CONTROL

The use of field control effects still greater savings in rheostatic losses, first, by reaching the motor curve at lower speed and, second, by operating on resistance a smaller portion of the time between the series and parallel positions. The usual method of weakening the field of a series motor is by tapping the field so as to cut out part of the effective turns. It is not good practice ordinarily to shunt the field, as it renders the motor much more liable to flashing.

The motor curves for the 600 volt locomotives for the Pennsylvania-New York Terminal are shown in Fig. 3. They show a wide range of speed covered by varying the field strength, and illustrate the possibilities of the series motor to meet the characteristics of the steam locomotive, which is able to develop its maximum horsepower over a wide range of speed. The author believes that the electric locomotive can be designed to perform practically any service that a given steam locomotive is capable of doing and will, in general, do it better, notwithstanding the tremendous improvements that have been made in steam locomotives in recent years. The Pennsylvania locomotive curves, for instance, show that it will develop an output of 1200 horse-power at any speed between 42 and 70 m.p.h. It will develop 1600 h-p over a range of speed from 36 to 60 m.p.h., or 2000 h-p between 32 and 52 m.p.h.; it will develop 3000 h-p over a range from 27 to 41 m.p.h., or 4000 h-p from 25 to 35 m.p.h. If locomotives are to be compared simply on the basis of the continuous or the one-hour rating, comparisons are likely to be misleading. The speed control shown on the curves for the Pennsylvania locomotives is quite within the range of possibility for well-designed direct-current locomotives and, while it is admitted that the electric locomotive does not entirely meet the speed-torque characteristic of the steam locomotive, which seems to be so desirable for express service, the writer believes that there are few cases where such a characteristic is necessary over the wide range of speed for any considerable length of time. In cases where a heavy tractive effort is required for short periods of time, the electric locomotive has the enormous superiority of being able to handle the load at a higher speed.

It is obvious that the rheostatic losses, with a locomotive having characteristics like those of the Pennsylvania locomotive will be so small as to be of very little importance, especially if a locomotive with four motors giving series, series-parallel and parallel control with variations in field strength is adopted. One example from the Pennsylvania locomotive curve will show the reduction in rheostatic losses that is made by the use of field control in parallel only. Assuming that

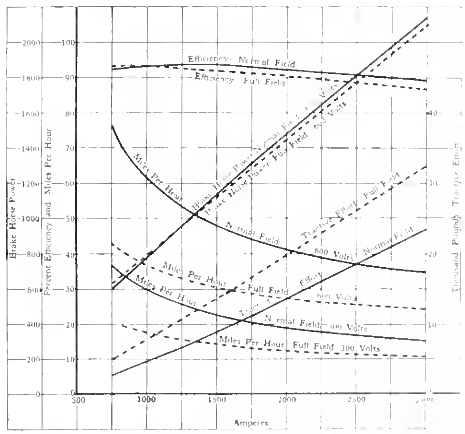

FIG. 3—WESTINGHOUSE NO. 315A RAILWAY MOTOR, 600 VOLTS, 72 INCH WHEELS, FIELD CONTROL

The usual series-parallel connections, combined with field control, give four speed curves. These curves simply show the maximum range of speed at which the motor is designed to operate at normal and half voltages, but there are two intermediate speed curves on each voltage which may be used, if desired, between the full field and the normal field position.

the locomotive for normal operation must have a speed curve as shown by the normal field, and that it is accelerated at a tractive effort of 40 000 lbs., the motor curve would be reached at a speed of 36 m.p.h. without field control, or a speed of 27.5 m.p.h. with the same tractive effort and field control. According to Fig. 2, the

rheostatic loss would be 24 watthours per ton in the one case and 13.8 for the other. If the field control were utilized with the series connection as well, the locomotive would be accelerated from a speed of 13.5 to 18 m.p.h. without resistance in the circuit, and a further reduction of nearly 3.5 watthours per ton-mile would be made.

Ordinarily it may be assumed as certain that the use of a properly designed field control equipment will reduce the rheostatic losses to not more than one-half of those encountered with series-parallel operation. The total saving per ton-mile will, of course, depend on the number of accelerations made, and the amount of low-speed operation which may require the equipment to be operated with resistance in series.

In general, the motor with a steep speed curve is to be recommended either with or without field control wherever the service requires frequent accelerations or very heavy grades are encountered. The saturated field motor, or the one having the flat speed curve, is to be recommended for use only where it is desirable to obtain a more nearly constant speed over long runs, regardless of variations in grades and trailing loads. Such a curve entails much greater fluctuations in load on the motors, reduces their overload capacity, and also increases the fluctuations on the line and substations. It is a mistake to think that the field control motor will be materially heavier for a given service than the simpler form of series motor, especially if the service requires frequent stops. It may have a lower rating for a given weight of motor, but in a class of service where the duty is confined to accelerating work, as is commonly the case in city and suburban lines, the motor with field control will be very little heavier than a straight series motor.

REGENERATION

Considerable savings can be effected by regenerating during the stopping period the power that is stored in a moving train, and also by saving the energy developed by the train in descending grades, which is now expended in wearing out brake-shoes and wheel tires. As 50 percent of the total power taken from the line is expended in this way on many lines, it is a matter of great importance.

The scheme adopted long ago on the Central London Railway, of saving this energy by elevating the station tracks is one that can be tried in special cases with excellent results. It has one great advantage over any scheme of electrical regeneration in that it adds nothing to the equipment and makes the work easier, so that smaller motors may be used. However, it has its limitations. It will be seen from Fig. 4 that a train operating at 30 m.p.h. would stop without brakes if allowed to climb to a height of 30 ft. A 14 ft. elevation would be required to absorb all of the energy in a train moving at 20 m.p.h. Of course, it would not be feasible to save all of the stored energy nor, in fact, would it be feasible to save any large part of it on a line having long trains and a high schedule speed. That it is possible to make very considerable savings, however, is shown both on the Central London Railway and on the South Side line of the Chicago Elevated Railway. Such a plan for saving power as this is not practical for the large majority of railways, but any scheme of electrical regeneration may be supplemented by the elevated station tracks.

A scheme of regeneration is already developed, involving the use of the standard series motor, with separate excitation during regenerative periods. The control may be entirely automatic from the time it is applied until the lowest speed is reached at which the motors when connected in series can develop the line voltage. At the same time it can be stopped at any desired speed. The regeneration at high speed is with the motors connected in parallel, and the change from parallel to series is effected by a bridging method especially adapted to this purpose. There is no break in the retardation of the train from the maximum speed until it comes to a standstill, for the control is so arranged that the air brakes may be applied as soon as the minimum regenerating speed is reached. The use of the standard series motor in this connection is of the great-

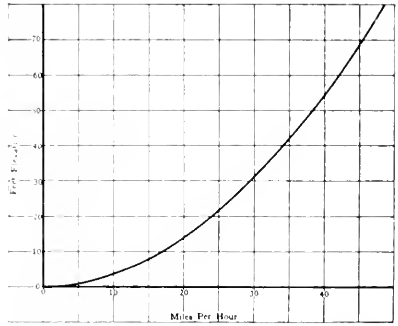

FIG. 4—TRACK ELEVATION REQUIRED TO BRING A TRAIN TO REST

est importance. The motor designed for field control also assists in securing the maximum saving of energy due to the fact that the regeneration can be carried to a lower speed.

It is usual practice in equipments for heavy multiple-unit service for city and suburban traffic to have the motors geared for a speed of about 15 to 18 m.p.h. at the one-hour rating of the motors. Such an equipment will retard the train by regeneration down to a speed of eight to ten m.p.h. Fig. 5 shows the possible saving that can be effected by regenerating down to a speed of ten m.p.h. Owing to the fact that the equipment required to permit regeneration adds somewhat to the weight of the car, the net saving in power will be somewhat less than that shown. A single example will show about what may be expected from this system. At a speed of 25 m.p.h. the amount of stored energy is 19 watthours per ton. The curve indicates that not less than 12 watthours per ton will be restored to the line. The additional weight of the equipment may bring the net saving down to 10 watthours per ton with the size of equipments on which these curves are based. Smaller and less efficient equip-

ments might reduce the saving to a still lower value, but it is probable that in any case at least 45 percent of the stored energy can be returned to the line. If this stored energy amounts to 50 percent of the power taken from the line, the net reduction in power consumption should be more than 20 percent. It is quite practicable to apply this method not only for the automatic retardation, as described above, but for use in controlling locomotives in descending grades. Perfect hand control can be obtained, together with a variation in speed, which makes the equipment even more desirable than the automatic regeneration of the three-phase induction motor.

LINE VOLTAGE

Up to 1905 there was very little tendency to increase the voltage of direct-current railways much beyond 600 volts, which had been virtually adopted as standard for city railways of all kinds. For a long time the limit to the voltage was in the insulation; later it was in commutation, but of late years the methods of insulation and materials available are so much better that they no longer form a limit to the voltage, and the use of

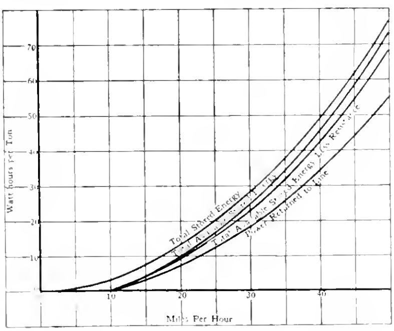

FIG. 5—ANALYSIS OF POWER REGENERATION, REGENERATING TO 10 MILES PER HOUR

The top curve shows the amount of energy that is stored in the car. From that is deducted the amount left in the car at a speed of ten m.p.h The next curve deducts the amount that is required to overcome train resistance at a specified rate of braking down to ten m.p.h. From this curve is deducted the amount of power that is lost in the equipment during regeneration. In this case the efficiency of regeneration is assumed to be 80 percent, which allows for a considerable loss in the auxiliaries. The lowest curve shows the energy in watthours per ton that should be restored to the line under the specified conditions from any speed under fifty m.p.h. down to ten.

commutating-pole motors has, in a great measure, eliminated the question of commutation from the limiting features. The consequence is that the line voltage has been pushed higher and higher. In the United States 1200 and 1500 volts have become the standard for interurban railways, while 2400 and 3000 volts are being used in two or three instances in trunk line electrification. In England 1200 and 1500 volt lines are now in successful operation and a 3500 volts experimental equipment has been in operation for several years. The highest voltage that has thus far been used is 5000 volts on an experimental equipment which has been operated, however, in regular service since June 1, 1915, at Jackson, Mich. In other parts of the world voltages of 750, 800 and 1000 are in use.

In view of the number of voltages already in use and the possibility of still higher voltages, the question of interchangeability of equipments has become very prominent. Two conditions of prime importance are necessary to enable equipments to operate interchangeably over different lines:—

1—The contact conductors must be so arranged that any equipment can take power from any line without change.

2—Every equipment must be so designed as to operate at required speeds over the various voltages of the different lines.

CONTACT AND COLLECTOR SYSTEM

Before any interchange of equipments is possible, it is necessary to standardize the contact system so that a car or locomotive from one line can collect current from a contact rail or trolley on any other line. The usual contact system for lines, except tramways using 800 volts or less, consists of some form of contact rail or rails mounted either outside of the running rails or between them. The oldest and most frequently seen is a top contact or over-running type of rail. To that has

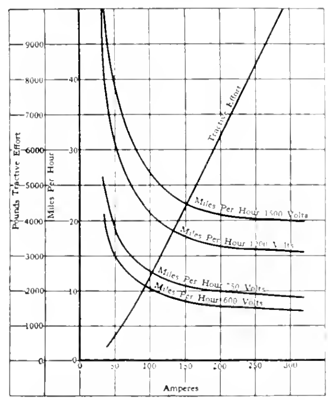

FIG. 6—SPEED CURVES AT VARIOUS VOLTAGES OF 250 HORSE-POWER (187.5 KW) RAILWAY MOTOR, NORMAL VOLTAGE 1500

been added a form of under-running rail and a new form of rail having a side contact. It is possible where the contact surfaces are properly located to have a single contact shoe satisfactory for collecting current from either the under-running or the over-running type of rail. Such interchangeability is possible between the Pennsylvania over-running rail and the New York Central under-running rail at New York. However, such things should be avoided if in any way possible.

The same statements hold true in regard to overhead conductors. The problem here is much simpler, because it seems to be the universal practice to locate the overhead conductor above the center line of the track and to keep its height between certain definite limits, which must in all cases clear the rolling stock. In this case it is more a question of adopting the proper kind of contact shoe.

MOTORS

A direct-current armature has practically the same current capacity regardless of the voltage applied to its

terminals, the latter being limited to a certain maximum, as determined by commutation characteristics and speed. Furthermore, increasing the voltage for a given current also increases the core loss, but this is largely compensated for by an increased speed which gives greater ventilation, especially with self-ventilating motors. It may, therefore, be assumed that the power rating of the motors is proportional to the voltage applied to its armature terminals, and hence that the normal capacity can be secured only by maintaining the normal rated voltage on the armature terminals. This, then, is the basis on which any proposition that involves interchanging equipments on different voltages must stand. It will be seen at once that the most advantageous results may be secured if the various line voltages are multiples of the rated voltage of the individual armatures, so that they may be connected in various combinations, depending

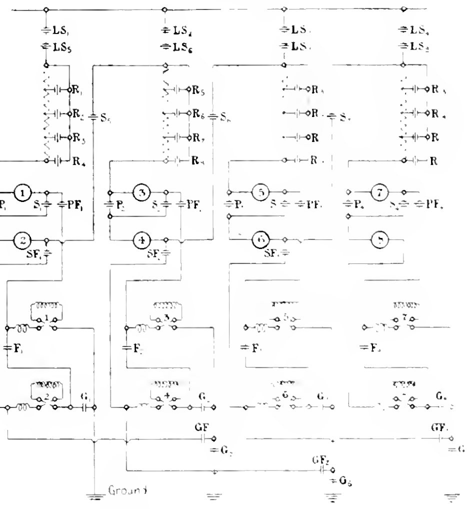

FIG. 7—DIAGRAM OF CONNECTIONS

By which eight armatures may be operated, four in series, two in parallel; two in series, four in parallel; or all in parallel, corresponding to full speed on 2400, 1200 and 600 volts, or full speed on 4800, 2400, 1200 and half speed on 600 volts. There are shown a total of 50 switches on this diagram, most of which would have to be designed and insulated to handle the maximum voltage. It indicates a comparatively complicated equipment in spite of the fact that the diagram is made up in its simplest form.

on the line voltage. To obtain the rated output from motors operating on multiple voltages, it is necessary so to manipulate the control circuits that each armature will always receive the same running voltage regardless of the line voltage, and there must be enough armatures in the equipment to permit so grouping them as not to impress more than the normal voltage on any one armature.

As 600 volts is recognized as the standard voltage for most city and suburban railways, the natural or desirable higher voltages adopted or proposed are usually 1200, 2400, 3600 and 4800. As most of the so-called 1200 volt lines operate with a substation voltage of 1300 to 1350 volts, practically the same equipments can be used on the 1500 volt lines, which offers, from the substation and line loss standpoint, a considerable advantage over the nominal 1200 volts. The speed curves that will be secured on a motor designed for a normal voltage of 1500 when operated at lower voltages are shown in Fig. 6. With a current of 150 amperes, giving a tractive effort of 4500 lbs., the speeds are 22.5, 17.6, 10.7 and 8.4 m.p.h., respectively, at 1500, 1200, 750 and 600 volts.

To consider the matter of interchangeability in specific instances the following examples are cited:—

1—Assume that the equipment is required to operate over a 600 volt line at full speed. The armatures must then be wound for 600 volts. It is also required to operate over 1200, 1500 and 2400 volt circuits. It will be seen at once that if series- parallel control is to be obtained at the high voltage, there must be two sets of motors, each set having four armatures connected in series, or a total of eight armatures. If these armatures are connected two in series on 1200 volts, full speed may be secured. On 1500 volts, however, it would be necessary to have the motors connected four in series, or to take a chance on raising the normal voltage on each armature to 750 volts. This would, in some instances, be possible as regards commutation, but would give 25 percent higher speed. Operating on 1500 volts

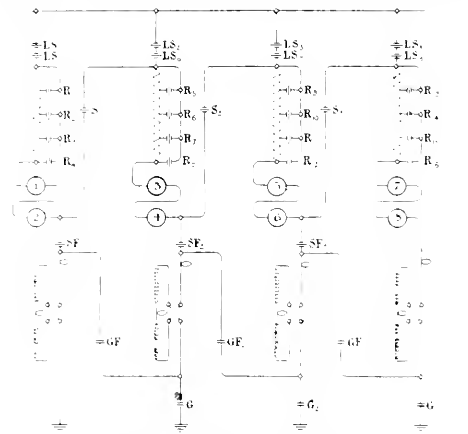

FIG. 8—DIAGRAM OF CONNECTIONS

With eight motors connected permanently two in series for full-speed operation on 2400 and 1200 volts, and half speed on 600 volts. This reduces the number of switches to 36.

with four armatures in series, as with 2400 volts, the speed and kw capacity would only be 62.5 percent of the normal, while on the other three voltages of 600, 1200 and 2400 it would be normal.

2—If equipments are required to operate over these same voltages but it is found that half speed on 600 volts is sufficient, as would be the case in many instances, the armatures would be wound for 1200 volts and full speed would be secured with series-parallel control on 2400 and 1200 volts, and 62.5 percent of normal speed on 1500 volts, unless it is advisable to take a chance on running a 1200 volt motor on 1500 volts. In this case only four armatures are needed for the equipment.

3—If it is required to operate at a maximum voltage of 3000, and also at 2400, 1500, 1200 and 600, it would be desirable to have at least four armatures in series on the higher voltage. The speeds for the different line voltages, then, with combinations of four in series, two in series, and all in parallel, with armatures wound for 750 volts, would give full output at 3000 and 1500 volts and 80 percent of the normal speed and output at 2400, 1200 and 600 volts. If only four armatures were used it would be desirable to connect them permanently in series on the 3000 volt system. This would probably be the case where equipments were designed primarily for operation on the lower voltages.

4—With 4800 volts on the line and four motors connected permanently in series at this voltage, full speed and output can be obtained with 2400 and 1200 volts and half speed at 600 volts; the output and speed at 3000 and 1500 volts will be 62.5 percent of normal.

The combinations which can be effected in this way are endless, but the above will show what may be expected in bad cases.

As illustrating what may be done to meet extraordinary conditions may be mentioned the 5000 volt car equipment at Jackson, Mich. This car operates over about 10 miles of suburban line with 5000 volts on the trolley, and also over two miles of 600 volt line in the city of Jackson. Series-parallel control is used on the 5000 volt connections, and a balancing speed of 50 m.p.h. is normally reached. On 600 volts the four sets of armatures are connected in parallel, and a speed of 18 to 20 m.p.h. is reached by shunting the fields of the motors. This speed is ample to make the schedule required in the city limits, and while the armatures are worked somewhat harder than usual, on account of the low voltage, the equipment is operating on this portion of the line so small a proportion of the time that the motors can easily stand the service. The writer believes that this method of operation can be followed successfully in a great many instances where equipments designed for high-voltage service are required to operate for short distances over low-voltage lines. It is quite practicable to shunt the motor fields down to a very low value in such cases, as there will be no danger of flashing at the low voltages.

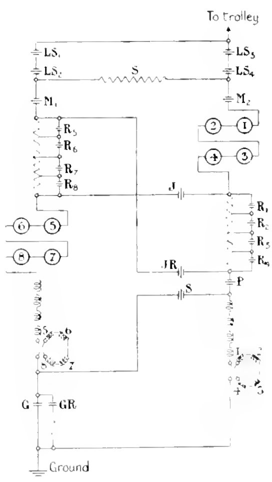

FIG. 9—HIGH-VOLTAGE EQUIPMENT

With eight armatures arranged for full-speed operation on one voltage only. The control is arranged for bridging control with the fields connected always to the ground side of the motors and requires only 20 switches.

It is undesirable to equip cars with more than four motors each, as the complication and cost would become too great. With the locomotive, however, it is quite practicable to operate with eight motors. As far as the motors themselves are concerned, there is very little additional complication from the necessity of interchangeability on different voltages. It simply requires the use of more armatures and at a greater cost than would otherwise be necessary. The motors, of course, would have to be insulated for the highest voltage on which they would be used. The complications introduced would be mainly in the control system.

CONTROL

The rate at which equipments are complicated by multiplying the number of voltages and combinations is indicated by Figs. 7, 8, 9 and 10. It is, of course, not necessary to use unit switches or contactors to effect all of these combinations, as drum type change-over switches are satisfactory in some cases for transferring connections when the current is off. Such a scheme is usually used for car equipments operating interchangeably on 600 and 1200 volts, Fig. 11 representing a standard arrangement for such an equipment. It will be noted that the change-over switch changes both motors and resistances from series to parallel, or vice versa. While such a scheme is quite satisfactory for lower voltages, especially for car equipments, it is generally considered better practice to arrange the motor circuits on high-voltage equipments so as to effect all changes possible by means of unit switches. All changes in voltage combinations can then be readily made by simply changing the control circuits. The use of unit switches exclusively for making combinations in the main motor circuits is sometimes carried to the extent of using them for reversers as well, especially for large locomotives. This has the advantage of maximum reliability and the smallest number of types of apparatus for the equipment.

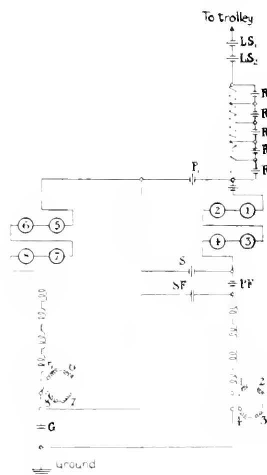

FIG. 10—HIGH-VOLTAGE EQUIPMENT

Arranged for full-speed operation on one voltage, shunt control. Eight motors are arranged for the shunting transition with only 13 switches.

The diagrams which have been shown are for the plain series motors operating only as motors without field control and without regeneration. The use of field control usually involves the use of two additional switches for each motor, unless two motors are connected permanently in series, when they can be controlled by the same number of switches as a single motor. Thus, a two-motor equipment on 600 volts can have the control equipments arranged for field control by the addition of two switches per motor, or a total of four switches for the equipment. A four-motor equipment arranged for use with two motors connected permanently in series can also obtain the advantages of field control by a total of four switches, but if the four motors are ever to be operated in full parallel, eight switches will be necessary. Where eight motors are to be operated with field control and arranged for full-speed operation on three voltages as 600, 1200 and 2400, 16 switches will be required for a single step. Much the same condition prevails where the equipments are arranged for regenerative control, and each additional switch means additional wiring for the equipment, both for the main motor circuits and for the operating circuits for the control.

It is not assumed that the number of switches which have been given in the preceding diagrams is the exact number that will be required for any given case. They are simply typical and comparative diagrams. In any case, however, the control circuits are apt to become very complicated where much change-over apparatus is required and an increased number of train line wires between the cars are necessary for multiple unit operation. That it is perfectly practicable to operate complicated control systems satisfactorily and reliably is shown by such examples as that of the New York, New Haven & Hartford locomotives, which operate both from 11 000 volt single-phase trolley and from the under-running 600 volt direct-current third rail of the New York Central system. The writer has seen many equipments operating on both alternating and direct current and has no desire to see that method of operation extended; but the control complications introduced by such an equipment are small compared with what would be involved in operating over three or four direct-current voltages with full speed on three of them and with several different forms of contact devices. There is no question but that the equipments can be arranged for successful operation in this way, but the additional first cost and the cost of maintenance would be so great as to be a serious handicap to electrical operation. It would be well-nigh impossible in any case to operate equipments from all the different lines in the same multiple unit train, since the difficulty of having the control interchangeable would be insurmountable. The simplest multiple unit equipments require from seven to twelve conductors in the train line cable, and in view of the fact that it is becoming usual to have train line wires not only for operating the switches governing the main circuits, but for controlling trolleys or contact shoes, lights, air compressors, signals, etc., the number of train line wires even for a single operating voltage sometimes exceeds 20. Two or three operating voltages would, therefore, multiply the number of train line cables so that possibly two or three would be necessary to effect satisfactory operation, and these would have to be the same on all equipments if the cars were to operate interchangeably in the same train.

AUXILIARY POWER EQUIPMENT

Every electrical equipment has several auxiliaries which are usually supplied with power from the main supply circuit. On 600 volts the air compressor motor, blower motor, if any, and lights are all supplied directly from the line.

Supplying the power for auxiliary circuits on equipments receiving power at several different voltages is one of the most annoying problems to be considered. Where only two voltages are encountered, such as 600 and 1200, it has been common practice to use a dynamotor on the higher voltage to reduce the line voltage to half its value for the auxiliaries. Double commutator auxiliary motors are sometimes used connected in series or parallel according as the line voltage is 1200 or 600. In this case the control and lighting currents are taken from the high-voltage circuit. Single commutator auxiliary motors are also sometimes used and run at half speed on 600 volts.

Any scheme involving operation over a wide range of voltage will necessarily complicate the equipment if it becomes necessary to operate continuously over any one of several line voltages. For the higher voltages it may be that the use of a storage battery, such as provided on the 5000 volt car equipment previously referred to, may prove to be the most satisfactory means.*

For locomotive use, where the auxiliaries require considerably greater power, it is quite feasible to use a motor generator to supply power to the auxiliaries. The motor should be series wound, so as to secure the greater stability due to that type of winding. In this case for supplying power from three voltages, as 2400, 1200 and 600, two motors, each wound for 1200 volts, could be used to drive a 600 volt generator, and connected in series or parallel according as the line voltage was 2400 or 1200. When operating on 600 volts the motor generator set would not be needed unless it were driving a blower, in which case the 600 volt generator could be used as a motor taking power from the line.

CONCLUSION

The logic of this entire paper points to the necessity for the early standardization of some of the more important features connected with electrification. The benefits of standardization would be immediately felt, not only in the greater security of the railways in embarking on a project of electrification, but in the decreased cost of all apparatus connected with it. If manufacturers could confine their efforts to the development of

*See article by Mr. N. W. Storer in the JOURNAL for Oct., 1915, p. 445.

apparatus for one or two voltages only, and could build enough apparatus of one type to put it on a manufacturing basis, the cost would be greatly reduced, and railways could save a large percentage of the present cost.

In a state with an autocratic government such matters could be decided by one man. In one with absolutely individual freedom of action, every railway might have its own set of standards. A better plan than either would be to secure the fullest co-operation of all concerned, carefully canvass the entire subject, and make definite recommendations for standards. The initiative in such an important matter should be taken by those engineering societies which number among their members the men who are necessary to decide such questions on their engineering merits. The writer does not advocate that everything connected with electrification should be standardized either immediately or in the near future, but he feels that such things as the location of the contact rail for third-rail systems and of a contact line for overhead systems could be settled within a short time;

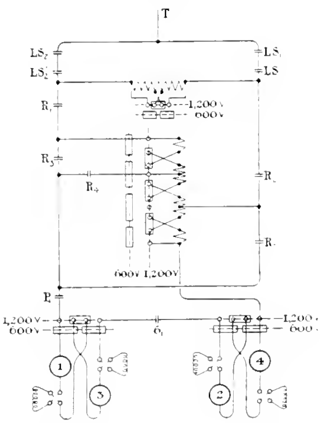

FIG. 11—DIAGRAM OF MAIN CIRCUITS FOR STANDARD HL CAR EQUIPMENT AT 600 AND 1200 VOLTS

also that the question of voltage can be decided before any further railways are electrified or extensions are made to existing direct-current systems. The former is more especially a question for the railways themselves to decide and is simply a matter of the railway men "getting together," but the latter is one for all engineers intereste l in electric railroading; and although it is somewhat beyond the scope of this paper, the writer will venture a suggestion concerning it.

Since the 600 volt system is so thoroughly established and also is so well suited to the requirements of terminal electrification, it should be continued as one of the standards, at least for the present. While it is probable that but little will be done towards the electrification of entire railway systems in the next few years, one other voltage should be selected that will be suitable for such service and will at least serve to direct the aim of those about to electrify. This voltage should be high enough to permit the heaviest drafts of power required to be collected from the overhead conductor without exceeding the capacity of a single wire or a single collector, and to reduce the amount of copper in the feeder system to the lowest value consistent with reliable distribution. If motor-generator or rotary converter substations are used, the number should be reduced as far as possible so as to secure a good load factor and thus decrease the cost and improve the efficiency. If the vapor converter proves to be a commercial apparatus for such work, substations may be placed economically at more frequent intervals. The determining factor in the entire question will, of course, be the cost, not only of the original installation, but of operation and maintenance. This will depend very largely on the electrical equipment of the locomotives and cars. It is obvious that the voltage will also depend on whether the equipments would be obliged to operate at full speed on 600 volts. If they are, it is practically useless to think of anything higher than 2400 volts. This may possibly be high enough for the maximum trains in Great Britain, but it is not considered high enough in the United States, as is proven by the fact that the Chicago, Milwaukee & St. Paul has adopted 3000 volts for their extensive system after a short experience with 2400 volts on the Butte, Anaconda & Pacific Railway. In this case the service is so heavy, although by no means the maximum that will be required in America, that it is still necessary to use two 4/0 trolley wires and a large amount of feeder copper. The writer believes that a still higher voltage should be adopted if direct current is to be used for trunk line service with such heavy trains.

It is generally conceded that 1500 volts is about the maximum that can be applied to the armature of a four-pole railway motor. Even with that voltage it is difficult to find space for the necessary number of commutator bars and brushholders, especially for small motors. It would, therefore, be necessary to connect more than two four-pole motors permanently in series for operation with more than 3000 volts. The type of motor used for the 5000 volt equipment which has been mentioned in the previous pages offers a solution for the problem which makes a very considerable increase in line voltage appear not only possible but easy, in so far as commutation and commutator bars are concerned. While this development has thus far not been carried far enough to prove the entire success of the 5000 volt direct-current system, it at least offers to those who desire a high direct-current voltage good ground for hoping for the realization of their wishes.

The writer suggests that, if possible, the through lines should be differentiated from the purely suburban lines, and that the best voltage for the former should be adopted regardless of the latter; and that an overhead contact wire, in addition to the 600 volt third rail, be placed over each track that requires full-speed operation for both equipments. While such a scheme has its disadvantages, they are negligible compared with the complication of equipments necessitated by the interchangeable operation on several different voltages.

Methods of Figuring Costs

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The figuring of correct costs is one of the most difficult of the many problems confronting the management of every manufacturing industry. The elements involved are labor and material actually expended either directly or indirectly; the direct expenditures are rather easily obtained, but the indirect expenditures have so many ramifications as to be quite bewildering, especially when there is a diversity of manufactured products. However, it will be evident after a moment's consideration that accuracy in costkeeping is an essential factor in the successful conduct of any business; it may, in fact, be said to be the cornerstone of the entire accounting system of a company, and unless properly laid the whole fabric of accounting, no matter how perfectly worked out in other respects, will be practically worthless.

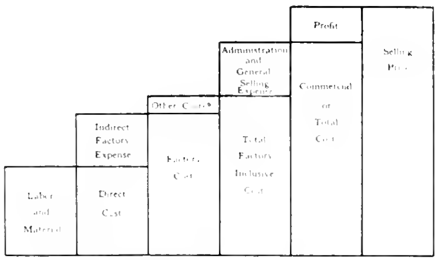
The only reason a business concern has for its existence is to make money for its stockholders, and in order to do this a profit must be made on its wares; that is, the total selling prices must exceed the total costs, but without a system of figuring costs correctly the actual profit cannot be ascertained. While it is a comparatively easy matter to determine the total cost of all apparatus en masse built in a given period of time, it is almost a physical impossibility to determine the exact cost of any particular piece. The cost of the material required can usually be calculated from drawings, etc., as can the wages of the workers actually engaged in the building; but the indirect expenses, consisting of both labor and material, such as heat, light, foreman's supervision, etc., which must also be taken into account, are very difficult to allot properly and with exactness to the various classes of apparatus. For example, assuming that the charges for heating and lighting a department as a whole could be determined, how can these charges be distributed, together with the foreman's salary, proportionately among the orders for apparatus going through that department?

There are five steps, as shown in Fig. 1, involved in arriving at the selling price of an order; namely, determining first, the direct cost; second, the factory cost; third, the total factory inclusive cost (so called for want of a better name); fourth, the commercial or total cost, and fifth, the selling price. The direct cost consists of the wages of the actual workers and the direct material cost; the factory cost is the direct cost plus a certain amount to cover indirect factory expense; the total inclusive cost is the factory cost plus an additional amount to cover any adjustment on completed orders or factory expense, development cost, etc. This may or may not be an important item. The commercial or total cost is the total factory inclusive cost plus a certain amount to cover administration, royalty and general selling expense; the selling price is the commercial or total cost plus a certain amount to cover profit.

Neglecting for the moment such items as total inclusive cost, royalty, administration and general selling expense, how can the indirect factory expense be distributed among the various orders? There are many ways of doing this, several of which are in general use, and it is these which will be briefly touched upon here.

DIRECT LABOR COST METHOD

The first method is known as the percentage on direct labor cost method. Under it the indirect expense of a piece of apparatus or production order, including both labor and material, is figured as a percentage of the direct labor. To ascertain what such percentage should be, all of the indirect expense in the works is totaled over a given period, say one year; likewise, the wages (direct labor) of all of the employees engaged



*Includes Adjustment on both Factory Expense and Complete Manufacturing Orders, Development Cost, etc.

FIG. 1—ANALYSIS OF TOTAL COSTS AND SELLING PRICE

on apparatus or production orders during the same time; that is, the wages of those directly at work in the building of apparatus (not, however, including the wages of truckers, elevator men, crane men or the like, which should be considered as items of indirect expense). The ratio between such totals of indirect expense and the wages (direct labor) is considered as the percentage to be used in connection with every order for apparatus being built, until such time as it is deemed advisable to check again to see if this ratio has changed. To apply this method of figuring costs to an individual piece of apparatus or production order, it is necessary simply to multiply the direct labor of the order by this percentage and add to the product the cost both of the direct labor and of the material used, when the factory cost of the order will then be obtained.

The method is based upon the principle that the product increases in value as money in the form of wages or direct labor is expended upon it; and the greater the amount of money thus expended, the greater the indirect expense of supervision, management, etc. This may, of course, be quite fallacious reasoning at times, for imagine two workmen, one skilled, the other un-

skilled, being given similar jobs to do. The skilled workman needs no supervision, while the unskilled workman requires considerable, yet both jobs are increased by the same percentage to cover the indirect factory expense. Again, simply by placing on a job a workman with a lower hourly rate than had previously been the case, the indirect factory expense is at the same time assumed to be reduced and, therefore, the cost of the job is reduced, which, of course, is erroneous. Still again, the tools used on two jobs may be widely different, hence the first cost, interest charges, depreciation, floor space occupied (and, therefore, heat, light, rent), power and crane service required, insurance, etc., would be radically different, yet under this system of figuring costs, all of these differences are at best applied in a rather unscientific manner.

The cost of the raw materials as received at the works is usually increased by a few percent to cover the cost of handling in the storerooms preparatory to their use in the manufacturing departments.

As the preceding method of figuring costs is perhaps more common than any other; and further, as most others in use are but variations of this one, it will be

TABLE I

\$100	direct labor,
40	raw material,
\$140	direct cost,
20	indirect factory expense (100 × 0.20),
\$160	factory cost,
8	commercial expense (160 × 0.05),
\$168	total cost,
25.20	15 percent added for profit (168 × 0.15),
\$193.20	selling price.

advisable to discuss the method more fully by actually applying it in the compilation of the cost of a representative order in a small manufacturing concern.

Examining, therefore, the records of such a company, it is seen there have been spent on all completed orders during the past year,—

\$100 000	total for wages (direct labor),
40 000	total for raw materials,
20 000	total for indirect factory expense,
\$160 000	total factory cost, and
\$8000	total commercial expense (selling, administration, royalty).

With reference to so-called raw materials, it will usually not do to charge them against individual apparatus or production orders at the same cost as they were purchased from the manufacturers, for the reason that they have to be handled both when being received into the storekeeping department after being purchased and again when being issued to the factory for subsequent use in the building of apparatus; there are such further items as shrinkage, loss, wastage, etc., with which to contend. Good accounting, therefore, requires that the necessary percentage, perhaps one or two percent, be added to the original cost to cover these additional items, and such may be added (as shown to be advisable) either by the storekeeping department before being issued to the factory, or by the factory before making up the cost of individual apparatus or production orders.

The first step, as was stated, is to find the ratio between the total indirect factory expense and the total wages or direct labor. It is seen to be one-fifth, or 20 percent; therefore, the actual indirect factory expense which each individual apparatus or production order is to bear thereafter, say for the following year, will be 20 percent of the wages or direct labor. Any difference between the assigned and the actual indirect factory expense must be regularly cleared, and this is accomplished by debiting or crediting such difference monthly or annually, as may be decided upon, either to a suspense account or to profit and loss, as the case may require. This same explanation applies to all methods of disposing of indirect factory expense upon a percentage basis.

The factory cost is, however, not the total cost. There are other expenses of quite a different kind still to be included in order to obtain the total cost, which cannot be charged against a particular piece or class of apparatus. These must, therefore, also be charged indirectly, neglecting adjustment on completed orders or factory expense, development cost, etc.; they are known as commercial or selling, administration and royalty expenses. As in the case of indirect factory expense, there are a variety of ways in which such expenses may be absorbed; but perhaps the most commonly employed method is to proportion them as a percentage of factory cost. Reverting again to the records of the company under discussion, the commercial expenses during the past year are seen to have totaled \$8000. This is five percent of the total factory cost of \$160 000; so to the factory cost of each individual apparatus or production order for the following year will be added five percent to cover commercial expenses, etc., thus giving the total or commercial cost of such an order when delivered on board cars at the works for shipment to a customer.

Suppose now it is desired to ascertain the commercial cost by this method of a certain completed order (Table I). Getting together first all of the workmen's time slips which bear the particular order number, these are added and found to equal, say \$100. This item is then the wages or direct labor cost. From the drawings the quantities and kinds of materials used are next ascertained, and the values of these calculated on the basis of prices furnished by the purchasing and the storekeeping departments. In this case the materials total, for example \$40, and this is, therefore, the raw material cost. The total of these two items gives the direct cost. The indirect factory expense is, as previously determined, 20 percent of the wages or direct labor, or \$20. The factory cost of this order, neglecting adjustment, development, etc., consequently is made up of \$100 for wages or direct labor, \$40 for material and \$20 for indirect factory expense, making a total of \$160. Taking next five percent of the factory cost of \$160, or \$8, for the commercial expense connected with the order and adding this to \$160, totals \$168, for the commercial cost. The only item left still to be considered is

profit; and this, as may readily be supposed, is generally figured on the total or commercial cost. Taking it at 15 percent of $168, or $25.20, and adding it to the commercial cost of $168, makes the selling price $193.20 for the order under discussion.

If, instead of being a small company, the concern in question were a very large one, the method just described would probably be deviated from to some extent. The company would, perhaps, be considered as several small independent concerns, housed together under one roof for certain mutual advantages, and the scheme outlined then applied to each section independently of the others.

DIRECT LABOR HOURS METHOD

The second method of figuring costs is called the direct labor hours method. It is quite similar to the one just described except that the hours (instead of the wages) put in by the actual workers are totaled over a certain period, and the ratio then found between the total indirect factory expense and the total hours. This ratio, which gives a value in cents per hour, say ten cents, is used as a multiplying factor, the number of hours expended on any order by the actual workers being multiplied by it to give the indirect factory expense connected with that order. If, for example, a workman whose rate is 20 cents per hour works five hours on a job, the actual wages would be 20 × 5, or $1. The indirect expense at 10 cents per hour for five hours would be $0.50. Here the theory is that the indirect expense is a function of the time; that is, an unskilled workman will take a longer time than a skilled workman and, therefore, the indirect expense should be proportioned accordingly. This method is an improvement over the percentage on direct labor cost method in substituting, as it does, time taken for labor cost, and thus showing that the longer a job continues in work the more expensive it is. However, no distinction is made between the tools used, whether large and expensive and, therefore, occupying more floor space, requiring more power, light and heat, having greater interest or depreciation charges, etc., or whether small and inexpensive and, consequently, involving such charges to a lesser degree. It also is thus far short of meeting the requirements of an accurate cost system.

DIRECT LABOR AND MATERIAL COST METHOD

A third method of figuring costs is known as the percentage on direct labor and material method, and is identical with the percentage on direct labor cost method, except that the indirect factory expense is proportioned on the total cost of the labor and the material together. It will be evident that if there are two orders having the same total of labor and material, but with a wide variation in the material used, one order being nearly all material, while the other is nearly all labor, this method would give extremely inaccurate results. The cost would apparently be the same, but it is obvious that the one requiring the more labor was in reality the more expensive to build. This method has an extremely limited application, as it can be applied only to such items as have a small amount of labor performed on them and where the methods involved are similar in practically all respects.

MACHINE RATE METHOD

Still another method, and the most scientific of all, is the new machine rate method. Under this scheme the indirect factory expense items are charged to the machines and processes to which they properly belong. The total for each machine and process is then divided by the total estimated working hours of such machine and process during this same period, the result giving an hourly indirect expense rate to each machine and process quite independent of the workman's hourly rate, so that if a workman whose rate is 30 cents per hour spends five hours operating a certain machine, the hourly indirect expense of which is $1.60, the total direct labor and the total indirect expense of that operation would be respectively 0.30 × 5, or $1.50, and 1.60 × 5, or $8.00, or a total of $9.50. It is, however, impossible to segregate all of the indirect expense directly to machines and processes so the unallotted portion or the general indirect expense, such as foremen's and clerks' salaries, which are common to all tools and processes, is divided by the total estimated working hours of all the tools and processes during the period selected, and the quotient then used as a common supplementary rate to be added to the hourly indirect expense rate of each machine and process; or, the general indirect expense may be figured as a percentage by which the indirect expense cost of the output from each machine and process must be increased to give the total indirect expense cost of the product, which is, of course, practically the same thing.

Since it would be impracticable in a works of any considerable size to apply hourly indirect expense and supplementary rates to every individual machine and process, the equipment may be divided into a number of groups, the machines and processes being then assigned to the group to which each naturally belongs, even though separated geographically, and taking accordingly the hourly rate of all other machines and processes in the same group.

In practice the estimated and the actual hours worked by any machine or process would seldom, if ever, be in agreement, so that allowances are therefore necessary for such difference. Assuming the total actual hours worked by all machines and processes to have been less than estimated, this difficulty may be overcome by totaling the indirect expense of the entire factory for a given period, say a month, and subtracting from it the total indirect expense directly chargeable to all of the various machines and processes for the hours actually worked during such period (number of hours worked multiplied by the hourly rates of the respective machines and processes), the difference being the indirect expense common to all machines and processes, including that due to idle time and, therefore, to be borne by all machines and processes in actual use. This difference is then divided by the total hours actually worked by all of the machines and processes combined, and the resulting

hourly rate will be the actual supplementary rate. The difference between it and the estimated supplementary rate will have to be added to the estimated supplementary rate to be used for the month following, unless, of course, the compilation of costs can be held up until the end of each month, at least as far as the supplementary rate is concerned, in which event the correct supplementary rate can be obtained. Judgment must naturally be exercised in applying these supplementary rates. For example, in a period of business depression, when perhaps but a small number are at work, it will not do to make a few tools bear the entire expense due to the idleness of all the rest of the equipment; for if this was done, the factory cost of any items produced under such abnormal conditions would be so high as to preclude its being sold. The proper solution in such instances is to figure the supplementary rate as in normal times as far as tools actually at work are concerned, then to charge the unabsorbed expense due to idle equipment against incomes or profit and loss account.

ment on which interest is figured should be decreased in the proportion in which the depreciation accumulates after the first year. For example, if a tool costs $2200, and interest is to be taken at six percent while depreciation is assumed at ten percent, then the interest during the first year after its purchase is $132 and the depreciation $220. The interest during the second year is taken at six percent on $1980 ($2200 — $220), giving $118.80, while the depreciation continues at $220. When these two items are included with the other items shown in this example as going to make up the cost of an article and a profit of, say fifteen percent, is then added to such cost, it is to be particularly noted that not only has six percent or $132 been made on the investment, but fifteen percent has in addition been made on the six percent interest ($132) as well; likewise fifteen percent on the ten percent depreciation ($220). Some concerns prefer not to include interest in the cost but, after the cost has been ascertained, to add an amount to the selling price to compensate. Depreciation is, however, almost invariably included, since it is considered more like an item of repairs. Obviously, of two concerns using these methods, the one excluding the interest from the cost at first, by compensating for it subsequently in the selling price, would come a little nearer to absolute accuracy in figuring costs.

Item 3—Computed in this example for ease in calculation at the rate of 10 percent per annum on the original value of the tool. Certain concerns depreciate a tool immediately upon its purchase, and then continue the depreciation by a further small annual percentage of the original value. The best way is to depreciate a tool at once to a certain percentage of the original cost

TABLE II.

PRODUCTION UNIT	Value of Equipment	Interest	Depreciation	Repairs, etc.	Actual floor Space	Working Floor Space—sq. ft.	Value of Working Space	Small Tools and Supplies	Horse-Power	Cost of Power	Cost of Light	Cost of Heat	Cost of Insurance on Tools, etc	Estimated Working Hours	Total Distributed Expenses	Undistributed Expense	Indirect Expense Rate per Hour	Assigned Rate per Hour	Supplementary Rate per Hour
																	Cts.	Cts.	
Planer—36"x36"x10'	$2200	$132	$220	$ 7	7' x 12'	160	$32.	$25	7 5	$352.50	$14 67	$16.	$4 40	2500	$803 57		32 1	32	2.15 Cts.
Shaper—24"	650	37	65.	3.	53"x50"	35	7.	10.	5	188	3.21	3 50	1 30	2000	320.01		16.0	16	
Lathe—18"x10'	750.	45.	75.	5.	3' x 12'	70	14.	30.	4 25	199 75	6 42	7.	1.50	2500	383.67		15.3	15	
Bench—3'x10'	100	6	10	1.	3' x 30'	180	36.				16 51	18	0 20	2500	87 71		3 5	4	
Floor Hands—(1)						180	36.	50.			16 51	18		2500	120 51		4 8	5	
Lathe—24"x12'	1500	90	150	12	42"x 14'	95	19.	20.	7 5	352 50	8 71	9 50	3	2500	664 71		26 5	27	
Sensitive Dr.—4 sp.	300.	18	30.	2	32"x50"	25	5	5.	1 5	56 40	2.29	2.50	0 60	2000	121 79		6 0	6	
Forge—3'x3'	60.	36	6	1.	3' x 3'	20	4.	6.			1 83	2.	0 12	2500	25 63		1.0	1	
Milling Mach. No. 3	900.	54	90.	6.	5'x 80"	65	13.	50	5.0	198 81	5 96	6 50	1 80	2115	426 07		20 1	20	
Radial Drill—4'	1000.	60.	100.	6.	3' x 7'	40	8.	40	3 5	118.44	3 67	4.	2.	1800	342 11		19 0	19	
Lathe—14"x6'	700.	42	70	10.	39"x93"	50	10.	25	3 5	131.60	4 58	5	1 40	2000	299 58		14 9	15	
Unused Space						580	116.				53 19	58.				$227 19			
Driving Motor—40 Hp.	600.	36.	Included in No. 10		Overhead Suspension														
Lighting	210.	12 60	Included in No. 11																
Heating	375.	22 50	Included in No. 12																
Miscellaneous				Included in No. 16												255.			
Total						1500	$300		37.75					24915		$537.29			
Items—(See Text)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

There are variations in details from the preceding general scheme; but, as already stated, it is the most scientific method of figuring costs yet devised, and on this account well worth while outlining rather more fully. Assume then that it is desired to investigate a small manufacturing establishment with respect to the proper indirect expense and supplementary rates which should be assigned to each unit of its equipment. The equipment is listed as shown in Table II, together with the principal items connected either with the building itself or with the equipment. Certain items have, however been omitted in the example taken, simply to avoid making it too cumbersome, but any such are to be treated in one of the ways set forth for the items described. The method of arriving at the values set opposite each is as follows:—

Item 1—Taken from the bills rendered by the manufacturer or builder of the tool.

Item 2—Computed at the rate of six percent. It should be noted, however, that whenever both interest and depreciation are to be taken into consideration in the same item the invest-

sufficient to represent a price that could probably be obtained if the necessity arose for disposing of it in the immediate future, then to depreciate thereafter at a fixed percentage of the remaining value each year, depending upon the assumed life of the tool.

Item 4—Estimated from cost of repairs during preceding period for tools of each class, as shapers, planers, etc.

Item 5—Taken from actual measurements of floor space occupied by each tool, including overhang of parts.

Item 6—Assumed at about twice the actual floor space occupied by each tool, though it can be fairly closely measured, but will vary to some extent with the class of work.

Item 7—Cost of building 30 by 50 ft. = 1500 sq. ft. = $3000.

Interest	6	percent	10 percent.
Depreciation	0	"	
Repairs	2	"	
Taxes	1.8	"	
Insurance	0.2	"	

$3000 \times 0.10 = \$300$, interest on investment, including taxes, repairs, insurance. $300 \div 1500 = \$0.20$, value per sq. ft. of floor space. It will be noticed that nothing has been allowed for depreciation, since the building is new and two percent has been allowed for repairs. Later, depreciation as well as repairs should be taken into account.

Item 8—Estimated from cost of all small tools and supplies during preceding period.

Item 9—Horse-power given by the manufacturer or builder of the tool.

Item 10—Power is arbitrarily assumed to be purchased at two cents per kw-hr and the total consumption is read from a meter; additional to this, the cost of certain other items must be included. The motor is supported in the overhead construction of the building, so no allowance need be made for floor space occupied. It will be observed that the capacity of the motor is 40 horse-power, and the machine tools when all running at full load require 37¾ horse-power, plus 15 percent loss, or a total of 44.4 horse-power; however, the assumption is made, and it is a fair one, that they practically never run at full load at the same time, or when they do, the motor is capable of standing this amount of overloading. The tools take, all told, 85 000 horse-power-hours (cols. *9* and *14*) during the year, but allowing a loss of, say 15 percent, in line shafting and motor, the total power consumption as read on the meter is 100 000 horse-power-hours, or 75 000 kw-hrs. This power cost must be further increased by interest, depreciation and insurance on the cost of the motor and its accessories.

75 000 = meter reading in kilowatt-hours for the year.

75 000 × 0.02 = $1500, cost of power for the year at 2 cents per kilowatt-hour.

$600 = cost of motor and accessories.

Interest	6 percent	
Depreciation	10 "	16.2 percent.
Insurance	0.2 "	

600 × 0.162 = $97.20, interest, depreciation and insurance on cost of motor and accessories.

$1500.00	
97.20	
0.80	oil, etc.
$1598.00	total cost of power for the year.

$1598.00 ÷ 85 000 = $0.0188, total cost of power per horse-power-hour. The horse-power of each tool as listed in column *9*, multiplied by the total cost per horse-power-hour, and this product multiplied in turn by the estimated working hours per year as listed in column *14*, gives the total cost for power for each tool for the year, as shown in column *10*. Similar remarks apply to interest and depreciation as were referred to under item *1*.

Item 11—Arbitrarily assumed at 14 cents per sq. ft. for installation; also 8.33 cents per sq. ft. for operation and maintenance per year. 1500 × 0.14 = $210, cost of installation for lamps and wiring. 210 × 0.06 = $12.60, interest on cost of installation of lamps and wiring. $12.60 ÷ 1500 = $0.0084, interest charge per sq. ft. for lamps and wiring.

$0.0084	
0.0833	
$0.0917	total charge for lighting per sq. ft. per year.

The square feet of working space required by each tool as listed in column *6*, multiplied by the total charge per sq. ft., gives the total cost for light for each tool for the year, as shown in column *11*.

Item 12—Heat is purchased from an outside concern and is arbitrarily assumed to cost 25 cents per sq. ft. for piping and installation; also 8.5 cents per sq. ft. for operation and maintenance per year. 1500 × 0.25 = $375, cost of installation and piping. 375 × 0.06 = $22.50, interest on cost of installation and piping. $22.50 ÷ 1500 = $0.015, interest charge per sq. ft.

$0.015	
0.085	
$0.100	total cost for heating per sq. ft. per year.

The square feet of working floor space required by each tool as listed in column *6*, multiplied by the total cost per sq. ft., gives the total cost for heat for each tool for the year, as shown in column *12*.

Item 13—Arbitrarily assumed at two percent on the value of the tool; insurance on building, finished product, etc., should likewise be allowed for.

Item 14—Estimated from preceding period or from a knowledge of incoming business.

Item 15—Obtained by the addition of the items in columns *2, 3, 4, 7, 8, 10, 11, 12, 13*.

Item 16—Obtained by the addition of the items in columns *7, 11, 12*.

Item 17—Obtained by the division of the item for each tool in column *15* by the corresponding item in column *14*.

Item 18—The nearest higher whole number to that given in column *17*.

Item 19—Obtained by dividing the total in column *16* by the total in column *14*.

As an example of the application of the preceding rates, any job done on the planer would have charged against it, not only the workman's hourly wage rate, say 40 cents, but a machine rate of 32 cents per hour and a supplementary rate of 2.15 cents per hour; thus,—

5 hours at 40	cents =	$2.00
5 hours at 32	cents =	1.60
5 hours at 2.15	cents =	0.1075
		$3.7075

The more shop charges are assigned to machines and processes, the greater the accuracy with which such charges are distributed; and, the more frequently they are revised, the greater will naturally be the value of this method of figuring costs. In case this method was just being applied in a factory, and it was not possible to hold up the compiling of costs until the end of the month, the total indirect expense of the entire factory for the first month would have to be estimated either from past performance or otherwise; likewise, the indirect expense directly chargeable to each and all machines and processes, as well as the hours to be worked by each and all. The totals of the estimated indirect expense directly chargeable to all machines and processes would then be subtracted from the total estimated indirect expense of the entire factory. This difference, when divided by the total estimated hours worked by all of the machines and processes, would be the temporary supplementary hourly rate. A provisional indirect hourly expense rate for each machine and process would next be arrived at by dividing the estimated indirect expense directly chargeable to same by the estimated hours to be worked by each, which hourly rate would be used for every job done on the machine or process to which it applied.

The time spent on every job by a machine or process during this first month would then be multiplied both by the indirect hourly expense rate and the supplementary rate, and the cost of each job compiled on this basis, including, of course, the wages (direct labor) actually paid to the workmen and the material cost. At the end of the month the total actual indirect expense of the entire factory could be obtained, and from it the total estimated indirect expense directly chargeable to all machines and processes (found in the manner described) subtracted from it. This difference would then constitute the unabsorbed indirect expense for the month. It would, in consequence, be necessary to absorb it by at once increasing the supplementary hourly rate of the preceding month sufficiently to include it, and using this supplementary hourly rate for the following month. At the same time any revisions necessary in the indirect hourly expense rates could likewise be made.

This modification will be slightly less accurate than the original method in which the supplementary rate is applied to costs during the month in which it occurred, whereas in the modified scheme the supplementary rate would always be applied to the succeeding month; but, in the majority of cases in actual practice, this is probably what would have to be done.

A 480 Point Testing Regulator

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Westinghouse Electric & Mfg. Company

A HIGH-VOLTAGE testing set consists of a high-voltage testing transformer and a regulating device which is connected to the supply circuit and which delivers a variable voltage to the low-tension side of the testing transformer. Regulation is usually obtained by means of either the step type or the induction type regulator. Sometimes the variable voltage is obtained by means of a variable resistance or reactance connected in series with the low-tension side of the testing transformer, but for general testing this is not a very satisfactory method of controlling the voltage, because the voltage obtained with any given resistance in series with the transformer depends very largely upon the load delivered by the testing transformer.

A testing set using the induction regulator is shown diagramatically in Fig. 1. This type of outfit is easy to install, as few connecting wires are required. A perfectly smooth voltage curve is produced and there are no abrupt changes in the testing voltage. It has one bad feature, however. The inductance of an induction regulator is comparatively high, very much higher than that of a step type regulator, and a considerable amount of inductance in the testing circuit is quite objectionable for some classes of testing.

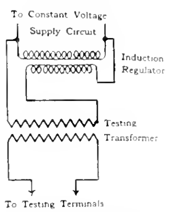

FIG. 1—SCHEMATIC DIAGRAM OF INDUCTION REGULATOR

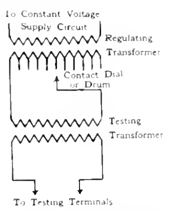

FIG. 2—SCHEMATIC DIAGRAM OF STEP TYPE REGULATOR

A testing set using a step type regulator is shown diagramatically in Fig. 2. It consists of the testing transformer, a regulating transformer with a number of taps in the secondary winding and a drum or dial type controller for transferring one lead of the low-tension winding of the testing transformer from tap to tap of the regulating transformer. It is evident that a perfectly smooth voltage curve cannot be obtained by this method, but that a number of abrupt changes in voltage will be produced, and the amount of each change will depend upon the number and the location of the taps on the regulating transformer. It is desirable to have a large number of steps in order that the change in voltage per step may be kept very low, but as the steps are increased in number a point is soon reached where the added cost and complications make further increase in the number of steps prohibitive.

The regulator shown in Fig. 3 overcomes the inherent limitations of the step type regulator by the use of "floating coils" in the regulating transformer. With these floating coils, although only 46 leads are brought out from the secondary of the regulating transformer, a total of 480 different voltages may be obtained, increasing in equal steps. This gives practically the equivalent of a smooth voltage curve, as the voltage change per step is only approximately one-fifth of one percent of the maximum voltage. Without the use of special instruments it is difficult to detect the small abrupt changes in voltages.

The scheme of operating can be understood by referring to Fig. 4. The secondary of the regulating transformers is divided into three parts. The main winding from *A* to *U* is divided into twenty equal parts with 21 taps marked *A*, *B*, *C*, *D*, etc. The floating coils *X* and *Y*, with winding development as shown, have taps so arranged that the voltage per step is equal to one-twenty-fourth of the voltage between adjacent taps (such as *A* to *B*) on the main coils *A* to *U*. By connecting lead *1* of coil *X* or lead *25* of coil *Y* to the proper tap on the main windings any one of 480 different voltages from zero to the maximum voltage can be obtained. For instance, with the top contact of the *F* drum, Fig. 5, making contact with finger *1*, and with the top contact of *S* drum touching finger *A*, zero voltage is impressed on the testing transformer. As the *F* drum is turned, fingers *2*, *3*, *4*, *5*, etc., to *12* successively touch the moving spiral of the *F* drum and the voltage is raised in steps of 1/480 of the maximum until on finger *12* the voltage impressed on the testing transformer is 11/480 of the maximum.

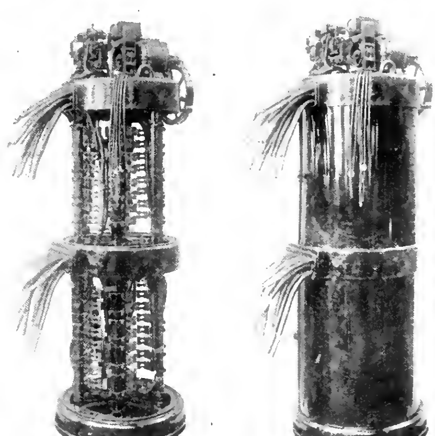

FIG. 3—STEP TYPE REGULATOR CONTACTS
With and without cover. The operating motor and brake are shown on top of the case.

In the meantime the *S* drum has also been slowly turning, so that *B* is now making contact with the lower spiral of the *S* drum and lead *25* of the floating coil *Y* is connected to lead *B* of the main winding. When the *F* drum makes contact with finger *13* the voltage on the testing transformer is increased to 12/480 of maximum.

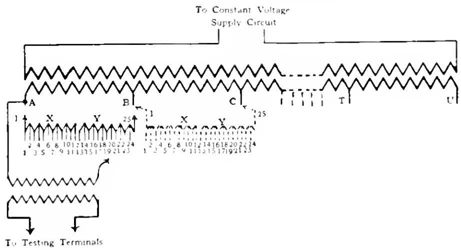

FIG. 4—SCHEMATIC DIAGRAM OF STEP TYPE REGULATOR WITH FLOATING COIL

That is, the voltage obtained is equal to the voltage of one step of the main coil *A* to *B* (1/20 or 24/480 of the maximum) minus the voltage from *13* to *25* of the floating coil *Y* (12/480 of the maximum), which equals 12/480. It should be noted that the polarity of the two floating coils is such that the voltage of the *X* coil is always additive, while that of the *Y* coil is always subtractive.

As the *F* drum is now turned to make contact successively with fingers *14*, *15*, *16*, etc., to *24*, the voltage is increased in steps of 1/480 of the maximum until when the drum makes contact with *24* the voltage is 23/480 of maximum. In the meantime the *S* drum has turned still further, so that the top spiral of the *S* drum no longer makes contact with *A*, but makes contact with *B*. As the *F* drum turns and makes contact successively with *1*, *2*, *3*, etc., again the voltages increase to 24/480, 25/480, 26/480, etc. This continues until the two spirals of the *S* drum make contact successively with fingers *A*, *B*, *C*, etc., to *U* and the *F* drum makes 20 revolutions, giving 480 voltage steps from zero to maximum.

The *F* drum has a double spiral, so that it will not be necessary to open the circuit in passing from one finger to the next. It is not permissible to let a single spiral touch two stationary contact fingers at the same time, as for example *1* and *2*, because in this case the section of the transformer between *1* and *2* would be short-circuited and probably burned out. A double spiral drum with a preventive resistance connected as shown is employed and the sequence of connection in passing from finger *1* to finger *2* is as follows:—Finger *1* first makes contact with top spiral and current passes directly to *L*. As the drum turns finger *2* makes contact with the lower spiral and current passes from *2* through preventive resistance to the transformer; also from *1* through *L* to the transformer. As the drum turns still further the contact is broken at finger *1*, and all the current passes from *2* through the resistance to the transformer. As the drum turns still farther finger *2* makes contact with the top spiral and the transfer from finger *1* to finger *2* is completed without opening the circuit or short-circuiting the two taps.

The motor-operated drum controller used for making the necessary change in connections is shown in Fig. 3. In the diagram of connections, Fig. 5, the two floating coils are not wound on the core of the regulating transformer as shown in the schematic diagram, but from the secondary of a separate auxiliary transformer, the primary of which is connected in parallel with the primary of the regulating transformer.

The controller consists essentially of two drums geared together by means of a double set of spur gears with a combined ratio of 24 to 1. In order to keep the controller as short as possible the contact fingers are arranged in six sets, which are mounted upon insulated supports equally spaced around the drums. The fast drum *F* is arranged to transfer the point *L* automatically to any one of the taps (*1* to *24*) from the two floating coils. The slow drum *S* acts as a transfer switch for the two floating coils connecting them alternately to the various taps from *A* to *U* as the regulator is operated from zero to the maximum voltage position.

The controller is operated by means of a small three-phase motor. A pinion on the motor operates a gear on a horizontal shaft, as shown in Figs. 3 and 5. This horizontal shaft is connected to the vertical shaft which supports the drum *F* by means of a set of bevel gears, which cannot be seen in Fig. 3, as they are mounted beneath the top cover. To prevent over-travel the motor is provided with a simple electric brake. The brake shoe and armature of the magnet are assembled and rigidly riveted together, and the two brake shoes with armatures are supported on two pins which are pressed into the motor bracket. The motor is operated by means of an electrically operated motor switch, also mounted on

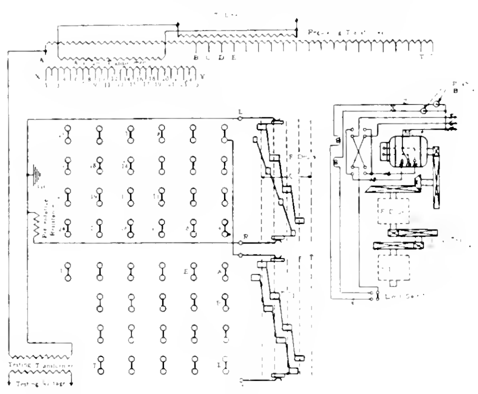

FIG. 5—CONNECTIONS OF REGULATOR DRUM SHOWN IN FIG. 3

top of the regulator. This motor switch is controlled by two push buttons, one for raising the voltage and the other for lowering the voltage. A limit switch located in the base interrupts the circuit to the motor switch at either limit of travel and prevents further operation of the regulator.

The Electrical Equipment of the Granite Mountain Hoist*

G. B. Rosenblatt and Wilfred Sykes

The hoist which has been operating on the Granite Mountain shaft of the North Butte (Montana) Mining Company since the middle of May, 1915, is the largest electrically-driven hoisting engine on the two American continents and ranks with the largest installations that have ever been made. On this installation particular attention has been given to economy of operation, reliability under all conditions and "Safety First." Previous hoists in this territory have been driven by steam or compressed air.† However, when the North Butte Mining Company put into operation the new Granite Mountain shaft it was decided to use an electrically-driven hoist. In all probability this new shaft will be sunk to a depth of 5000 feet. The equipment is designed to operate from this depth as a maximum, and will handle seven tons of ore per trip. The ordinary operating rope speed is 2700 feet per minute. The capacity of the hoist is approximately 300 tons per hour from the 2000 foot level, 250 tons from the 3000 foot level, and 200 tons from the 4000 foot level. The weight of the skip and cage is slightly more than 9000 pounds. The drums are 12 feet in diameter by 9 feet 4 inches face, with turned grooves to hold 5000 feet of rope in two layers. An indicator with a large dial is provided for each drum, and for accurately spotting the cage the brake rings on the drums are extended next to the middle bearing, affording a surface on which to paint marks.

The power required to accelerate the hoist and its load from standstill to the running speed of 2700 feet per minute depends, of course, on the rate of acceleration. In order to obtain the desired capacity it was necessary to figure on accelerating from standstill to full speed in about 16 seconds. The power required to accelerate is thus very greatly in excess of the power required to do the hoisting after full speed has been attained, as shown in Fig. 2.

The cost of purchased power for an average load of about 1500 horse-power with peaks of approximately 4500 horse-power, as would be required by a straight induction motor hoist, under the conditions obtaining in Butte would be prohibitive. It was, therefore, decided to use the Ilgner system, consisting of a direct-current shunt motor, supplied with power from an induction motor-generator flywheel set. A slip regulator is connected in the secondary of the induction motor in such a way as to limit the input to the motor. No attempt was made to install a flywheel of sufficient capacity to equalize the load completely, as the continuous losses would be very greatly increased by the use of such an excessively large flywheel. It was estimated that with a 50 ton flywheel the peak loads during normal operation could be limited to 1250 horse-power when hoisting from 2000 feet, 1420 horse-power for 3000 feet, and 1850 horse-power for 4000 feet. When the load exceeds the value for which the slip regulator is set, it automatically increases the resistance of the secondary circuit and slows down the motor, thereby allowing the flywheel to give up energy and carry the peak loads. When the load decreases, the motor again accelerates the flywheel, storing energy for the next trip.

The efficiency of hoisting by this system is not as good as if the power were utilized more directly. How-

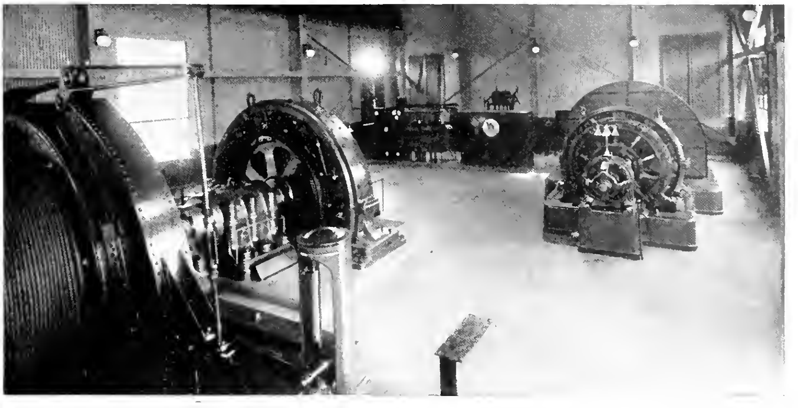

FIG. 1—GENERAL VIEW OF HOIST ROOM OF THE NORTH BUTTE MINING COMPANY

*Revised by the authors from papers presented before the A.I.E.E. and M.S.of E.

†See article by Mr. G. B. Rosenblatt on "Large Synchronous Motors for Compressor Service" in the Journal for March, 1912, p. 189.

ever, it was not theoretical efficiency that interested the mining company. Their object was to reduce the cost of hoisting per ton of ore lifted to the surface, and this, by the elimination of peaks, is accomplished to a greater extent than would be feasible with a hoist direct driven from an induction motor. Also, the elimination of the

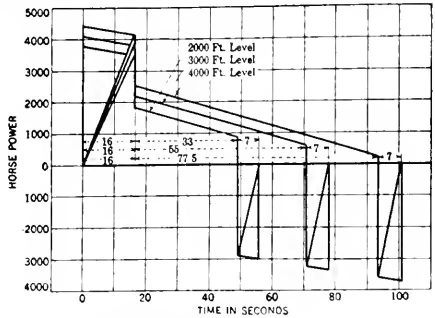

FIG. 2—POWER CONSUMPTION CURVES OF NORTH BUTTE MINING COMPANY'S HOIST

elaborate controlling apparatus which would be necessary with induction motor drive, and the absolute control over the speed of hoisting, form an additional compensation for the extra power required. The calculated efficiency of operation is shown in Fig. 3. Considerable importance was also attached to the reduction of the light load losses to a minimum, as the flywheel motor-generator set runs continuously, only shutting down about once a month for cleaning.

The hoist consists of two drums, each fitted with a clutch, post brake and band brake. The drums are mounted on a shaft supported by three bearings, the shaft having a flanged coupling to connect to the motor shaft. The clutches and post brakes are operated by oil cylinders, the pressure being supplied by an accumulator with an electrically-operated triplex pump. The band brakes are operated by hand wheels. All of the operating levers are grouped on a large elevated platform with double stairways. The control and reverse levers are separate, but are so interlocked that when the con-

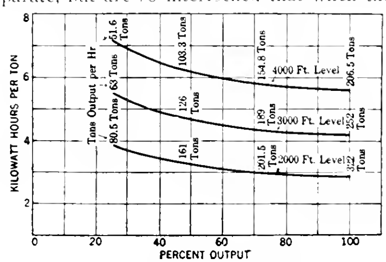

FIG. 3—EFFICIENCY OF OPERATION

trol lever is in the "on" position the reverse lever cannot be moved.

The hoist is driven by a 16 pole, 600 volt, 71 r.p.m., direct-current shunt motor, having a nominal continuous rating of 1850 horse-power, an intermittent rating of 2750 horse-power and is guaranteed to deliver 5000 horse-power for short periods without injury. Since the frequency of hoisting and the duration of the hoisting period is somewhat uncertain, particular care was taken to build a machine that would stand high temperatures without injury, and mica and asbestos insulation was used throughout the machine as a factor of safety, the insulation being such that an ultimate temperature of 150 degrees C. can be carried without injury. The total weight of the rotating part of the motor is approximately 70 000 pounds, and its radius of gyration is 4.1 feet. The motor is separately excited at 250 volts. Its efficiency is high for a machine of this type, as is shown by Fig. 4.

The motor-generator set is driven by a 1400 horse-power, 60 cycle, 2200 volt, 14 pole induction motor running at a maximum speed of about 505 r.p.m. The commutating-pole generator is designed to deliver about 6000 amperes during the period of acceleration at a maximum of 600 volts. It is connected directly to the hoist motor without switch or circuit-breaker, the speed and direction of rotation of the motor being controlled by means of the excitation on the generator. Its armature has a diameter of 66 inches and the field has ten poles, so that during acceleration 1200 amperes are collected at each brush arm. The generator is also arranged for separate excitation at 250 volts from the direct-connected exciter. A Tirrill regulator maintains the voltage of this exciter constant, despite the speed variations.

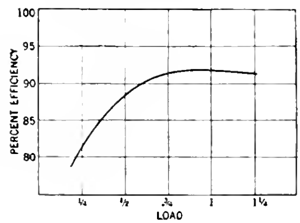

FIG. 4—EFFICIENCY CURVE OF HOIST MOTOR

Mounted between the motor and generator, as shown in Fig. 5, is a 12 foot flywheel weighing 50 tons. The peripheral speed of this flywheel will be as high as 10 000 feet per minute. In order to prevent any possibility of a flaw in the wheel it was assembled from segments of rolled steel plate, each sheet being one-half inch in thickness and cut to fit the wheel. These various plates were then assembled together to a total thickness of 21.5 inches and riveted, the number of rivets being such that there is sufficient pressure to hold any one plate by friction alone, thereby eliminating any dependence on the shearing stress of the rivets. The steel used in the wheel has an ultimate tensile strength of 60 000 pounds per square inch, which is many times greater than the maximum possible stress in the wheel. The flywheel and its shaft are built up as a unit, the shaft having a forged flanged coupling at each end, to which the motor and generator are coupled.

Naturally a flywheel of this size, presenting such a great area for air friction and running at such a high speed, will cause considerable windage. Windage is energy wasted in uselessly stirring up air and, in order to reduce it and thus increase the economy of the set, the

entire surface of the flywheel is very carefully finished. All rivets are counter-sunk flush with the surface. The entire wheel is carefully cut and finally polished and lacquered, so that it will present as smooth a surface to the air as possible, and thus reduce friction. Further, the amount of air that could possibly be moved by contact with the wheel is reduced by totally enclosing the wheel in a sheet steel case carefully finished on the inside and fitting as closely as possible about the flywheel. It was considered at one time that it might be advantageous to run the flywheel in a vacuum, but investigation proved that, while such operation was feasible, the application involved complications without sufficient increase in economy to compensate. Tests indicated that the friction and windage losses running the flywheel in the open air would be between 80 and 100 horse-power. By enclosing the wheel in a properly designed cover, these losses could be reduced to something like 50 horse-power. Excluding the air from the cover did not seem to reduce the losses by more than 12 or 15 horse-power, which saving in power would hardly pay for the application of the necessary water-sealed glands, air pump, and changes in case construction to resist the external atmospheric pressure.

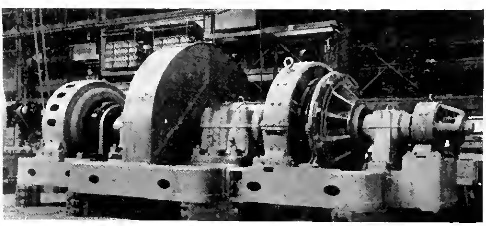

FIG. 5—MOTOR-GENERATOR FLYWHEEL SET

The bearings for the flywheel are 18 inches in diameter by 46 inches long. They are designed to be water-cooled, and are provided with gravity forced feed lubrication. Provision, however, is made so that they can be operated without water-cooling and without gravity feed lubrication in case of emergency should either the cooling system or the oiling system be temporarily disarranged through any accident.

The input to the induction motor driving the flywheel set running under regular hoisting conditions is shown in Fig. 7. The slip regulator limits the maximum input during each period to practically the same value. The load between trips drops down to practically the friction load of the set, indicating that the interval between trips is longer than is necessary to bring the flywheel up to full speed again. The work in a typical shift would include 131 trips hoisting ore, 36 trips hoisting waste, 13 trips with timber and 18 trips with men. Typical operating cycles under present conditions are shown in Fig. 8. The hoist at present is working from a depth of 2800 feet, and the acceleration peaks are not as high as they will be when working from a greater depth. The overall efficiency of the hoist, including all mechanical and shaft losses, as well as electrical losses—i. e., the ratio of input to the actual work to lift the material—is 48 percent. The light load losses, including the excitation for the hoist motor, are approximately 126 horse-power.

An electrically-driven hoist allows many safety devices to be applied which are difficult to incorporate

FIG. 6—CONTROL APPARATUS

with other types of hoists. The features to be particularly guarded against are careless operation, failure of power, and unforeseen accidents.

Under careless operation should be considered:—

Starting up too suddenly.
Overwinding.
Failure to apply brakes.
Overloading the equipment.
Overspeeding.

It is believed that this equipment is protected against any of these contingencies by the system of control installed. Most moderate size direct-current electric hoist motors are controlled by inserting resistance in series with the armature circuit. On this installation the speed of the hoist motor is controlled by varying the voltage supplied to the motor armature. The voltage is controlled by regulating the field of the direct-current generator of the motor-generator set. This field is controlled in about 30 steps by magnet switches operated by contacts on a controller manually actuated from the hoist platform. Its operation is, however, not placed entirely within the control of the hoist operator. The magnets of the magnet switches are interconnected amongst themselves through relays so that the operation of each successive magnet switch is, as you might say,

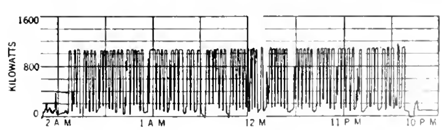

FIG. 7—WATTMETER CURVE
Showing input to motor driving flywheel motor-generator set

responsible for the operation of the next succeeding switch, and a current relay prevents them operating at any rate which would permit the hoist motor being speeded up too fast. Further, the hoist is provided with an overwinding and safety stop device provided with electric limit switches, which are also connected with the magnet switches.

With this combination of control devices, it is impossible for the operator to start the hoist too suddenly. The magnet switches are arranged so that they will not close at more than a predetermined speed. The operator may throw the controller to a position corresponding to any speed he desires and the motor will come up to and attain that speed, but only at a predetermined rate of acceleration.

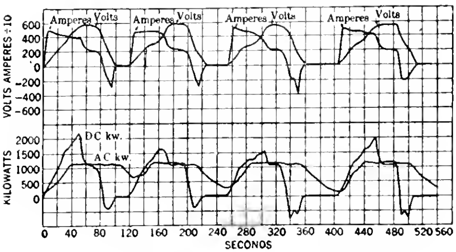

FIG. 8—TYPICAL OPERATING CYCLES

Overwinding is prevented by the operation of the Wessinger safety stop device, which is so connected with the controller that when a cage passes a predetermined point a certain distance below the collar of the shaft the controller automatically cuts resistance into the generator excitation circuit, gradually reducing the voltage, and consequently the speed of the hoist motor. If the operator in an emergency wants to stop the hoist quickly he can do so by deliberately plugging the motor, but the action would have to be deliberate, and could not readily be accomplished inadvertently in the ordinary course of operation.

Failure to apply brakes is taken care of both by operation of the Wessinger device and by equipping the system which operates the brakes with two electric magnets connected to emergency valves in the brake-operating system. These magnets are so connected that in certain emergencies their magnetism fails, causing the valves to apply the brakes.

It is rather difficult to overload an equipment of this sort, due to the fact that the capacity of the electrical machines is ample to take care of any load that can be put in the skips, and the control devices effectively prevent the equipment being speeded up too fast. For this reason the circuit from the direct-current generator to the hoist motor is solidly connected without any switch or circuit-breaker between the two machines. Accordingly, in case of overload there is nothing to disrupt the service. What will, however, happen is that the slip regulator and the flywheel will get into action in case of overload and prevent the hoist motor from being supplied with more power than is good for it. The operator could, nevertheless, overload the hoist motor by trying to push past some impassible obstruction in the shaft, and to prevent any such possibility an overload relay is connected in the circuit between the direct-current generator and the hoist motor. This relay does not open the main circuit, but operates a circuit-breaker in the circuit controlling the field of the direct-current generator. The circuit-breaker is built with two poles, and in case the overload relay trips it one pole opens the generator field circuit, thus cutting off the excitation, while the other pole opens the circuit to the brake magnets, thus applying the brakes the moment the field circuit is broken.

Protection against overspeed is given largely by the type of motor used to drive the hoist. This is a separately excited shunt-wound machine. Unlike the ordinary series-wound motor used for smaller hoisting work, the speed of a shunt-wound motor is practically independent of the load. A series motor will speed up, often to a dangerous degree, if the load is removed. A shunt-wound motor will not do so. Its speed can only be increased by raising the voltage supplied to the armature or decreasing the excitation supplied to the field. The maximum voltage that can be supplied the armature on this particular installation is fixed by the maximum voltage that can be supplied by the generator of the motor-generator set. There is no way of raising this voltage to a degree that will permit dangerous overspeed. The amount by which the separately excited field of the hoist motor may be weakened is also very definitely limited. This field is excited, not from the main generator of the motor-generator set, but from the exciter generator mounted on the end of the motor-generator shaft. Its voltage is maintained constant by a Tirrill regulator. With full voltage across the hoist motor field the excitation is such as to permit a rope speed of 2700 feet per minute. For emergency operation it is possible to raise this rope speed to 3000 feet per minute by inserting a certain fixed resistance in the hoist motor field circuit, and thus weakening its excitation. This extra resistance can only be inserted in the hoist motor field by deliberate action of the operator—to insert this resistance and obtain speeds between 2700 feet per minute and 3000 feet per minute necessitates the deliberate operation of a latch on the hoist control platform. The only condition

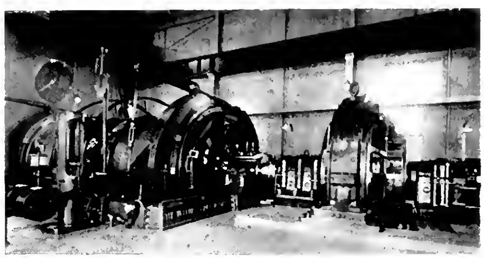

FIG. 9—GENERAL VIEW OF MAIN HOISTS

that would give a higher speed of the hoist motor would be a further weakening of the shunt field, and this could only be obtained by failure of the excitation circuit. The brake magnets previously mentioned are connected in the exciter circuit, and failure of the excitation would immediately set the brakes.

With the arrangement of electrical equipment selected, speed control is obtained on lowering in the same manner as it is obtained in hoisting, the motor in this

case acting as a shunt-wound generator, and as long as the motor is clutched to the drums the hoist cannot attain overspeed.

An interesting additional device furnished in connection with the speed control is a knife switch which may be thrown into action when hoisting workmen, and when thrown limits the value of the voltage that can be applied to the hoist motor armature to such a value as will give a predetermined safe speed. This speed may be adjusted to suit local conditions, and any speed up to this speed may be obtained when the knife switch is thrown. It simply fixes a value of speed which cannot be exceeded as long as the knife switch is closed.

Failure of power to the hoist may occur either because the power supply to the motor-generator set has been interrupted, or because one of the connections between the various pieces of apparatus has been broken. If the power supply to the motor-generator set fails the flywheel will continue to drive the set for a considerable period of time. The hoist may be operated for one or two trips with reduced loads at moderate speeds by using the energy stored in the flywheel. Power is supplied to the motor-generator set through a circuit-breaker equipped with no-voltage release, and this breaker will open in case of failure of power from the supply line. If power returns before the flywheel has lost very much speed all that is necessary is to reset the circuit-breaker. If, however, power remains off the line for a considerable period of time, so that the speed of the motor-generator set has dropped below a predetermined point, the excitation will fall and render the hoist-operating mechanism inoperative, at the same time releasing the brake magnets.

Protection against accidental failure, due to the breaking of any of the electrical connections between the various pieces of apparatus, is guarded against by making all of the control equipment operate by the application of power rather than depending for any operation upon the interruption of power. The brakes are locked by failure in any part of the excitation circuit. The main circuit from the direct-current generator to the hoist is, as stated above, tied together solidly without switch or circuit-breaker. There is, therefore, nothing in this circut to open, but should it be opened for any reason it can be arranged to operate the circuit-breaker in the brake magnet circuit, and thus apply the brakes It will thus be seen that the operation of the hoist is, therefore, well guarded against any accident due to failure of power.

The only other causes of possible accident are, therefore, unforeseen physical causes, such as the jamming of the cage in the shaft, fainting of the operator, or the like. The best that can be done is guard against the results of such accidents as have in the past been experienced. If the cage does jam in the shaft it will immediately operate the overload relay in the main circuit, which will trip the double-pole circuit-breaker in the excitation circuit, bringing the motor to rest and setting the brakes. If the operator does faint while a trip is in progress the overspeed and safety stop devices will slow the hoist down as the cage approached the collar of the shaft and will ultimately move the controller to the off position, gradually apply the brakes, bringing the motor to a standstill, and finally set the brakes tight by cutting off power to the solenoids attached to the emergency valves on the brake cylinders. The safety devices are all of the type that operate every time the hoist operates, and therefore are always in operating condition.

Automatic Change-Over Switches

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Westinghouse Electric & Mfg. Company

MAINTAINING continuous lighting service in or about electric railway company substations and waiting rooms, public and private office buildings, hospitals, etc., has made necessary the provision of means for switching over automatically to another source of power supply when the trolley or normal voltage is cut off or falls below a certain value, and for switching back automatically to the normal source of supply when its voltage has been restored or when it again reaches a sufficiently high value. Means should also be provided for holding the switch closed on the normal circuit in the event of any failure of the automatic switches or in case both sources of supply are interrupted, while at the same time providing for automatic connection of the lighting circuit to that line which is first energized at the required voltage. The prime requisites for such a switching equipment are simplicity and reliability. One having these characteristics is especially useful for isolated plants which have central station auxiliary service, for central station customers who receive power from two different distributing lines or to make possible the immediate switching to a battery for emergency service.

An automatic change-over switch which is suitable for changing from a direct-current circuit to another direct-current circuit at the same or a different voltage, or to an alternating-current circuit of any desired voltage, is shown in Fig. 1. It consists of two switching arms attached to a walking beam operated by a direct-current magnet, a magnet switch and resistance and a helical steel spring mounted on a slate base.

The connections of the switches and operating mechanism are shown in Fig. 2. Under normal voltage conditions line switch *No. 1* is held closed by the operating magnet. Should this voltage fall below a predetermined value, the spring overcomes the operating magnet and

closes the switch to line *No. 2;* at the same time (if it is desirable to so arrange the circuits) the top contact of the auxiliary switch closes the circuit of a signal bell.

As soon as the voltage of the normal supply circuit exceeds the predetermined minimum value, the direct-current magnet switch closes, thereby short-circuiting the resistance in series with the operating coil and ap-

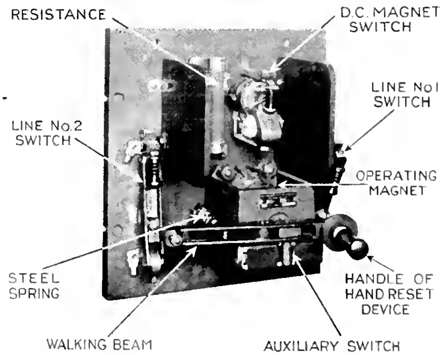

FIG. 1—AUTOMATIC CHANGE-OVER SWITCH FOR DIRECT-CURRENT NORMAL CIRCUIT AND DIRECT OR ALTERNATING CURRENT AUXILIARY CIRCUIT

plying full voltage across this coil and the magnet switch coil, whereupon the coil plunger, by overcoming the pull of the spring, closes the switch to line *No. 1.* The direct-current magnet switch is simultaneously short-circuited, and thereupon opens its contacts and cuts in a resistance which reduces the current through the operating coil to a value just sufficient to hold this coil closed. Approximately 100 watts is required at normal line voltage to hold the switch closed on line *No. 1.* This group of switches contains all the advantages of a robust mechanism with low power consumption for operation.

In change-over switches, it is imperative that the arc be extinguished in one switch gap before the other switch closes. In the switch shown in Fig. 1 the contacts travel a sufficient distance to insure the opening of

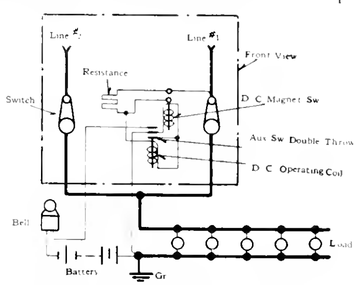

FIG. 2—SCHEMATIC DIAGRAM OF AUTOMATIC SWITCH SHOWN IN FIG. 1

The line *No. 1* is held closed under normal conditions by the operating magnet. The direct-current magnetic switch is adjusted to cut out the resistance at such a voltage as the direct-current operating coil will close; this then closes the auxiliary switch, cuts out the magnetic switch and cuts in the resistance. When the voltage fails on line *No. 1,* the switch on line *No. 2* is closed by the spring, and the bell alarm contact is made on the auxiliary switch.

one circuit before the other is closed, and barriers isolate the arc. In some instances it may be found desirable to supplement this air break with a magnetic blowout.

When the normal source of supply is alternating current and the auxiliary supply is direct current, an alter-

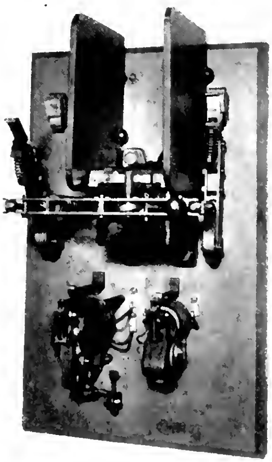

FIG. 3—AUTOMATIC CHANGE-OVER SWITCH FOR ALTERNATING-CURRENT NORMAL CIRCUIT AND DIRECT-CURRENT AUXILIARY CIRCUIT

nating-current, under-voltage relay is provided, as shown in Figs. 3 and 4. The switch arm is normally held closed by a spring, but when the normal supply fails, then the under-voltage relay closes the direct-current magnetic switch circuit, which in turn closes the direct-current operating coil, and from this on the sequence of operation is the same as for the switch previously described. When the alternating-current supply circuit again has normal voltage impressed on it, the

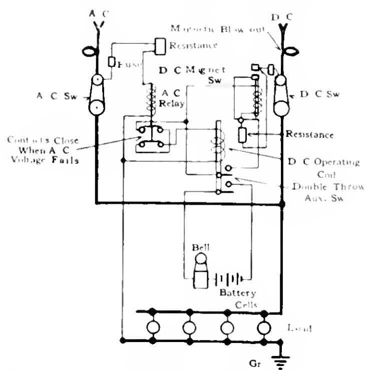

FIG. 4—SCHEMATIC DIAGRAM OF CONNECTIONS OF SWITCH SHOWN IN FIG. 3

The alternating-current switch is normally held closed by a spring. When the alternating-current voltage fails, the direct-current switch is closed by the operating coil and rings the bell.

under-voltage relay opens the control circuit of the direct-current switch and the spring closes the alternating-current switch.

ENGINEERING NOTES

Three-Phase Power-Factor from Wattmeter Readings

Three-phase power-factor on balanced circuits equal the watts divided by $\sqrt{3}\,EI$. When a power-factor meter or the necessary ammeters and voltmeters are not available, the power-factor may be determined from the readings of two single-phase wattmeters by any of the following formulae, in which W_1 is the reading of the wattmeter giving the smaller indication and W_2 the reading of the wattmeter giving the larger indication with a lagging power-factor, and $X = W_1 \div W_2$, the current and voltages being approximately balanced.

$$\text{Power-factor} = 1/2\sqrt{\frac{3(1+X)}{1+X^2}}$$

A more convenient form of the same equation is

$$\text{Power-factor} = \frac{1+X}{2\sqrt{1-X+X^2}}$$

Still another form is

$$\text{Power-factor} = \frac{1}{\sqrt{1+3\left(\frac{1-X}{1+X}\right)^2}}$$

An equation involving the actual wattmeter readings instead of a ratio is

$$\text{Power-factor} = \frac{1}{\sqrt{1+3\left(\frac{W_2-W_1}{W_2+W_1}\right)^2}}$$

If a table of natural functions is available the following formula is convenient:—

$$\operatorname{Tan}\phi = \frac{\sqrt{3}\,(W_2-W_1)}{W_2+W_1}$$, from which $\cos\phi$ is obtained by means of the table.

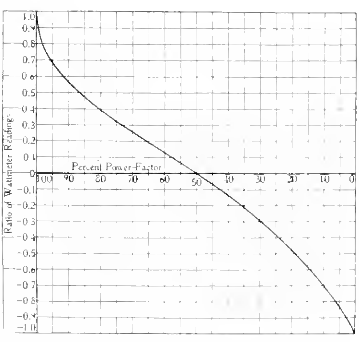

FIG. 1—RELATION OF POWER-FACTOR TO RATIO OF WATTMETER READINGS

Probably the most convenient method of all is to substitute the value of X in the curve given in Fig. 1. While an exceedingly accurate reading cannot be obtained from a curve in this way the accuracy of the reading will probably equal the accuracy of the method itself.

Reactance

Reactance in any circuit is due to magnetic flux linking with the circuit. Wherever an alternating flux links a conductor an e.m.f. is generated in the conductor, regardless of whether the flux is furnished by some outside source or by current in the conductor. If it is furnished by current in the conductor it will be in phase with the current which causes it. As this flux cuts the conductor it will induce in it an e.m.f. which will be 90 degrees behind the flux, since the e.m.f. is proportional to the rate of change of flux which is maximum when the flux is passing through zero, if the flux is a sine wave. Thus the counter e.m.f. is 90 degrees behind the current. It is this counter e.m.f. that is called reactance drop, and the reactance expressed in ohms is equal to the reactance drop (volts) divided by the current (amperes).

This agrees with the ordinary definition of reactance, $X = 2\pi fL$. Reactive drop is $IX = (2\pi fL)I$. Self induction, L, is defined as $L = \frac{n\phi}{I}$ so that reactive drop $IX = \frac{2\pi f n\phi I}{I} = 2\pi n f\phi$ which is the voltage generated in the circuit of n turns by a flux ϕ of frequency f. In a word, reactive drop is a counter e.m.f.

Cast-In vs. Bolted Poles

In the early types of multi-polar generators, the laminated poles were cast into the frame, but this method of construction has become obsolete, having been superseded by bolted-in poles. When casting the poles into the frame a special form was used for holding the poles in the sand to insure their proper spacing. These poles were made without extended tips, for the field coils had to be formed and then slipped on over the poles, being held in place by hangers attached to the pole pieces and the frame. After the machine was assembled a field coil could be removed only by taking the armature out of the stator and loosening the hangers. This made repair work very inconvenient. The great difficulty with these machines was in the adjustment of the air-gap. If the gap was to be increased the armature had to be removed and the necessary change made by reboring. It was practically impossible, however, to decrease the gap. The construction was an inflexible one from a manufacturing standpoint.

With the bolted-in poles most of the processes of manufacture and repair are greatly improved. The casting of the frame is a very simple operation, as the frame consists only of a circular form of iron or steel cast in one or two pieces, depending upon its size, and no thought need be given to the spacing of the poles. After the frame is cast, bored and assembled it is a very easy matter to correctly space the pole pieces.

The bolted-in poles are made with extended tips, the body being narrower than the face. By making the pole body of decreased section material is saved, both in the pole itself and particularly in the field winding. This decrease in section can be made, since the flux may be worked at a higher density in the pole body than in the pole faces, on account of flux distribution in the air-gap.

The field coils are formed and slipped over the pole body from the rear end, and are supported by the extended tips. The pole with its field coil is then fastened in place by tap bolts which extend through the frame into the pole body. If it becomes necessary to remove the field coils from the machine the tap bolts are removed and the poles can be taken out without disturbing the position of the armature. Liners, composed of sheet steel of any desired thickness, may be placed between the pole and the frame when the machine is assembled. The air-gap can then be readily changed, if necessary, by loosening the tap bolts and either removing some of the liners or adding others, as the case may require. It is therefore seen that easier methods of repair, simpler and more accurate construction and better support of the field coils have all had their weight in changing from cast to bolted-in pole construction.

B. H. LYTLE

THE JOURNAL QUESTION BOX

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To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1286—Transformers in Series—Two 20 k.v.a. transformers of modern make and similar in all respects are to be used with the connections shown in Fig. 1286(a) in order to secure 330 volts for the load R by connecting the latter between points *3b* and the half tap *2a*. The normal ratio of transformation for each transformer is 1100/220 volts when the full secondary

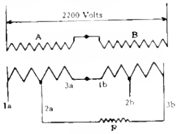

FIG. 1286(a)

winding *1-3* is in use. The following information is desired:—(a) With 2200 volts impressed on the two primaries in series, what will be the voltage across each primary, and each secondary? (b) Is there probability of dangerous voltage existing across any of the windings with full-load current in the secondaries? (c) Will distortion of the impressed voltage wave occur? J. C. C. (CALIF.)

The voltage across each secondary and across each primary for this connection depends upon the current delivered to the load R. At no load each of the primaries will have 1100 volts across them, and each of the secondaries will have an induced voltage of 220 volts from *1* to *3*. When current is taken by R, the ampere-turns of the combined secondaries will equal the ampere-turns of the combined primaries. As the transformers are connected in series the current must be the same in both. The primary load ampere-turns in transformer A is, therefore, one-third greater than the secondary ampere-turns; also in transformer B, the secondary ampere-turns is one-third greater than the primary load ampere-turns. The transformers act as reactances for these excess ampere-turns.

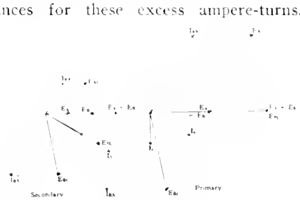

FIG. 1286(b)

The reactance voltage is equal to the voltage required to circulate an equivalent current through the primaries with the secondaries open circuited. This can best be shown by the following vector diagram and magnetization curve. Assume that R is drawing 40 k.v.a., this gives 100 percent load on the combined primaries, but gives an excess ampere-turns in the primary of A and secondary of B equivalent to 33 percent of full-load current. The magnetization curve shows that 33 percent current gives 150 percent voltage. In the vector primary diagram E_A or E_B is the counter e.m.f. of either primary, $E_A + E_B$ is the voltage across the two primaries, (2200 volts) I_0 is the magnetizing current. I_P is the primary load current. The reactance voltage in transformer A is due to the excess primary ampere-turns and is, therefore, 90 degrees ahead of the primary current. This is 150 percent voltage, and is represented by I_{AX}. The reactance voltage in transformer B is due to the excess ampere turns in the secondary and, therefore, 90 degrees behind the primary current. This is indicated by I_{BX}. The total voltage across the primary of A is the resultant of I_{AX} and E_A and equals E_{A_1} in the diagram. The resultant voltage across the primary of B is E_{B_1}. The vector diagram for the secondaries has been drawn to a larger scale. The letters in this correspond to

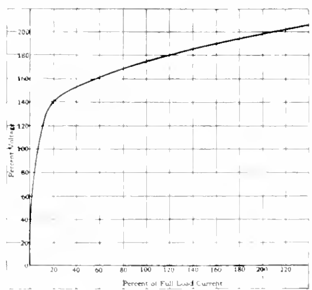

FIG. 1286(c)

similar values in the primary diagram. The reactance between the primaries and secondaries have been neglected in the above, as these are practically negligible. The above magnetization curve has been assumed and may not be correct for these particular transformers, as this curve varies considerably for different transformers. It will be seen from the foregoing that the voltages across the individual transformers may have dangerously high values, and may even be several times normal. Also, under these conditions, the cores will be highly saturated, which will result in the magnetizing current I_0 becoming excessive. On account of the highly magnetized iron, the current wave will have a badly distorted shape. This may also result in distorted voltage waves on both primary and secondary sides. J. F. P.

1287—Lightning Protection—In the *Journal of the (British) I.E.E.* of February 1, 1916, p. 294, appears a statement as follows:—"Surge effects do not cause much trouble on a large system and our experience has been that the less the amount of apparatus for protecting against surges the less is the trouble experienced. For the overhead lines we at present rely entirely on taking them into substations through a short length of underground cable. After the lightning storms last summer, statistics were prepared which showed the benefit of this in a striking manner. Nearly all cases of trouble occurred on overhead lines brought direct into substations; a few cases occurred where only short lengths of cable had been used, say 20 to 30 yards, while in those cases where longer lengths of cable had been used no trouble at all was experienced." Please explain why such a means of protection fulfills the same purpose as the protective apparatus usually employed for such service and what are the limiting considerations? H. E. T. (PENNA.)

By virtue of the electrostatic capacity between the leads of these cables and the grounded sheath of the cable, these lengths of cable acted as condenser lightning arresters. The longer lengths of cable afforded a greater degree of protection than the short lengths, because the greater lengths have a greater capacity to ground. The limiting considerations of an arrester of this form are the capacity and the dielectric strength of the cable, and the line constants. If the dielectric of the cable breaks down it means a short-circuit on the system, while if a more concentrated capacity is placed between each line and ground and it breaks down, the chance of a short circuit is greatly reduced. The greatest limitation of the condenser arrester has been the inability to obtain at a low price a condenser having the required capacity and a sufficiently high breakdown value. However, recent improvements in condensers bid fair to greatly reduce these limitations. Condenser arresters are now used to some extent on direct-current lines when lightning conditions are very severe. G. C. D.

1288—Graphic Wattmeter Connections—Please point out in Fig. 1288(a) the mistakes in the connection of the graphic recording wattmeter and power-factor meter. In their present position no reading is obtained on the wattmeter, and the power-factor meter is 180 degrees out. By reversing the leads at the terminals *1* and *2*, also *6* and *7*, a correct kilowatt reading is obtained. By changing the potential leads on the power-factor meter, it will read in the "lag" when it should "lead," and vice versa. By reversing B and C at the instrument, the power-factor meter will be read correctly. Again, assuming original position, when changing B and C at current transformers, no reading is obtained on the wattmeter and the power-factor is O.K. Then changing terminals *1* and *2*, the wattmeter reads correctly at unity power-factor, but can be made to read anything by varying the

power-factor. The power-factor meter will not rotate when the potential leads are removed. I assume this is caused by a mechanical defect in the instrument. F. E. M. (ONTARIO)

The graphic wattmeter connections shown in Fig. 1288 (a) would be correct if the direction of power were opposite to that shown by the arrow. For the direction of power indicated on the diagram it will be necessary to reverse the connections to the current coils in order to make the meter read in the right direction. The diagram shows the control circuit connected to one of the voltage transformers which supplies the meter element. This is not good practice. The control circuit should be supplied from a separate source. The power-factor meter is shown with its voltage coil connected to the wrong phase. One terminal of the voltage coil should connect to the same line as the current transformer which supplies the current terminal shown at the left in the diagram. If the voltage connection shown at the upper left terminal of the power-factor meter were changed to the other voltage transformer, the meter would read power-factor correctly on the lower half of scale, with direction of power as shown in diagram, or would give the same reading on upper part of scale with power supplied in the opposite direction. When connecting power-factor meters it should be remembered that their correct operation

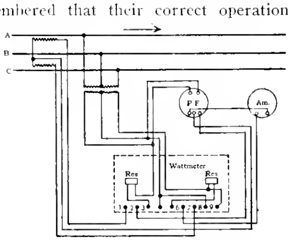

FIG. 1288(a)

depends upon having the current coils connected to the circuit so as to give a definite sequence of phases. The correctness of this connection is shown by the direction of rotation of the pointer on current alone. When this test is made, the load on the meter should be from 2.5 to 5 amperes in the five-ampere series coils. The failure of the meter movement to rotate on current alone may be due to mechanical defect or to insufficient current. A meter which requires three to four amperes per coil to produce rotation on current alone may have ample torque to read accurately when the voltage connection is made. Difficulty in obtaining correct operation of power-factor meters sometimes results from the belief that it is absolutely necessary that the middle current terminal of the meter shall connect to the common point of the two current transformers. The leads from two voltage transformers or two current transformers on a three-phase circuit when connected as shown should be considered in the same way as the three main conductors of the circuit. There is nothing peculiar about the lead connecting to the middle point of the transformers, and two of the leads should be interchanged if necessary to obtain correct sequence of phases, in the same way that the main conductors would be interchanged. H. B. T.

1289 — Electric Hoist Brakes — We have a single-drum cage hoist operated by an 85 horse-power wound rotor induction motor which is controlled by a reversible master controller and clapper board. In lowering we simply let the motor run backwards without any power on it and regulate the speed with the hand brake. In lowering a heavy load to the bottom of the shaft the brake becomes undesirably hot. Could a simple arrangement be made by which the motor could be made to do the braking going down? J. C. H. (ONTARIO)

By reversing the motor, it would act as an alternating-current generator and hold the speed at about the synchronous speed of the motor. In other words, the speed going down would not exceed the speed going up. There should be no resistance in the rotor circuit when this braking is being done. Inserting resistance would tend to increase the speed in lowering. There is no convenient way to brake from this full speed to rest by means of the motor. This would have to be taken care of by disconnecting the motor field and braking to rest by the mechanical brake. The only advantage of using the motor would be to limit the maximum speed at which the load would go down. It would not provide a means of stopping, but would decrease the heating of the brake. A. M. D.

1290—Heating in Lead-Covered Cables —If three 600 000 circ. mil, lead-covered, rubber-insulated cables are placed in a tile duct and these cables connected to a switchboard as a three-phase, 60 cycle installation, would the heating of the lead sheath be objectionable or dangerous? E. W. P. S. (OHIO)

The current which will flow in the lead sheath will reduce the carrying capacity by approximately 15 percent. If the frequency is 25 cycles, the reduction in carrying capacity is about five percent. If the cables are farther apart, the reduction in carrying capacity due to the presence of the sheath is greater. Also the reduction in carrying capacitv is approximately proportional to the thickness of the sheath, within commercial ranges; this data being based upon one-eighth inch thickness. If the current which flows from one sheath to another is forced to flow through a contact having a high resistance, much greater local heating, even (under some conditions) to the point of melting the lead, may result. This condition need not exist if the sheaths are connected thoroughly together at the two ends and if the spacing between the cables does not vary between these points. R. W. A.

1291—Railway Motor Air-Gap—What would be the approximate decrease in efficiency of the standard railway type series motor if the air-gap (between pole pieces and armature) were increased 10 percent due to rubbing the pole pieces on account of the bearings being worn out. I mean the decrease after bearings have been re-babbitted, with and without the iron losses (due to damage by rubbing) taken into consideration. I am endeavoring to determine at what point it would be most economical to substitute new pole pieces for the damaged ones; am assuming that average increase of air-gap is ten percent, as all pole pieces are not damaged. J. G. O. (PENNA.)

The increase in losses (and hence decrease in efficiency) due to the enlarged air-gap would be negligible compared with the increase due to the short-circuiting of the pole laminations from the rubbing of the armature. As these pole face losses take place within a very small fraction of an inch of the surface, it would not require much contact with the revolving armature to cause sufficient short-circuiting of the laminations to give large losses. These losses, in conjunction with the increased core losses due to damage to the armature teeth may cause sufficient increase in heating to be dangerous to the insulation. It would be practically impossible, however, to calculate these losses, as so much depends on the exact conditions of each individual machine, as well as on the general characteristics of the type of motor in question. J. W. S.

1292—Induction Motor Bearings—(a) What is the usual clearance in induction motor bearings when new, the shaft diameter being $1\frac{1}{8}$ inches? Approximately how much wear would a year's use, eight hours a day, be on a belted motor under ordinary conditions? (b) Would a loose bearing which causes unequal air-gap, but does not allow the rotor to touch the stator, have a tendency to increase the starting current of the motor? J. H. P. (CALIF.)

(a) Clearance expressed as maximum difference in size of shaft and bore which is permitted in manufacture is +0.003 inches minimum to +0.006 inches maximum. The usual clearance may average about +0.004 inches for bearings one to one and one-half inches diameter. The question as to the wear for one year's service cannot be answered definitely, as it depends on many factors, principally the bearing alloy, bronze, babbitt of different grades, the oil used, freedom from dirt and grit, length of bearing, belt tension, etc. On well-designed and well-kept bearings the wear in a year is practically zero, not more, at any rate, than 0.001 or 0.002 inches. (b) Ordinarily a slightly loose bearing would have no tendency to increase the starting current. C. W. S. and A. M. D.

1293 — Sizes of Alternating-Current Motors—(a) Are alternating-current motors built for 220 volts at 500 horse-power rating? (b) Are steam turbo-generators of 2000 k.v.a., three-phase, 60 cycle capacity built for as low a voltage as 220 volts? If so, what is the relative cost of such a unit? (c) Would it be cheaper to generate at 2200 volts and step down to 220 than to purchase the low-voltage generator? R. G. B. (PENNA.)

(a) There is little or no demand for motors as large as 500 horse-power for voltages as low as 220. (b) Turbo-generators of 2000 k.v.a., 60 cycle, 220 volt, 3600 r.p.m., have been built for special applications, usually for supplying low-voltage rotary converters. The cost of the low-voltage generator will be a little higher than a similar 2400 volt generator on account of the cost of the heavy copper armature cross connecting straps and leads, but this difference will not begin to pay for the transformers. (c) A 2400 volt generator and step-down transformers would be the best scheme if the current must be transmitted more than 100 feet from the generator. F. D. N.

1294—Meter Constant—I am placing a three-phase, five-ampere, 100 volt meter, with the potential transformer in the bus, at 2300 volts, and current transformer across a line of 11 000 volts, as shown in Fig. 1204(a). Can the reading be exact? And how should the reading be made of the meter, with 2300/100 volt potential transformers and 16 to 1 current transformers? I ask this question because I have no potential transformer for 11 000 volts.

M. S. (BRAZIL)

Assuming that the meter is a polyphase watthour meter connected so that the disc rotates forward on each element independently with 100 percent power-factor load, and assuming the transformer ratios and phase angle to hold for all conditions of load, 1000 watt-hours or one kilowatt-hour on the meter represents $\frac{2 \times 80 \times 11\,000}{1000} = 1760$ kilo-watt hours. If the meter has a one kilowatt-hour capacity counter, a multiplier

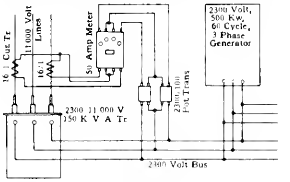

FIG. 1204(a)

of 1760 should be used. If the counter is any other capacity the multiplier should be $\frac{1760 \text{ kilowatts}}{\text{kw rating of the counter}}$. As connected, the meter measures its own voltage circuit losses. The greatest source of error would probably be due to the varying ratio and phase angle due to varying load. This answer assumes that the main transformer is connected Y-Y or △-△. If it is connected Y-△ or △-Y the meter phase angles will be incorrect.

C. R. R.

1295—Motors for Coal-Cutting Machines—Kindly let me know the size of motor (horse-power rating) generally used on coal-cutting machines. Are any made for use on alternating-current circuits? Please give an approximate method of estimating the rating (generally given in tons capacity) of a haulage motor, knowing the tons coal hauled, grade and speed. Also the size motor used in the range between 3 and 20 ton rating.

F. G. L. (W. VA.)

Usually 25 to 35 horse-power motors are used in coal-cutting machines. This rating is based on operating for one hour at 75 degrees rise. The motors are generally heavily compounded, 250 or 500 volt, direct-current motors. A number of companies are in a position to furnish alternating-current motors for operating coal-cutting machines. These motors have proved very successful, but require a little better voltage regulation than is necessary for the direct-current motor. The alternating-current motor loses torque rapidly with drop in voltage, while the direct-current motor does not lose torque, but drops in speed with a drop in voltage. For a method of estimating the weight and equipment of a mine locomotive see Vol. VIII, p. 986, and *Coal Age* for March 6 and March 20, 1915. The capacity of a motor equipment for mine locomotives varies somewhat with the size. For gathering locomotives ranging from 3.5 to 8 tons the total capacity of a motor equipment will range from 6 to 10 horse-power per ton. For main haulage locomotives ranging from 10 to 20 tons weight the total capacity of the motor equipment will range from 10 to 12 horse-power per ton.

G. B.

1296 — Electrically-Driven Flour Mill —I have been asked as to the best equipment to install to run an electrically-driven flour mill of about 1000 horse-power motor load. Having been greatly helped in other difficulties by your Question Box answers, I would like to be enlightened upon:—(1) Information as to efficiency and power-factor at full load and of starting torque of:—(a) Squirrel-cage induction motors. (b) Slip-ring induction motors. (c) Synchronous motors, self-starting and separately started. (2) In the event of using synchronous motors, what proportion of the total horse-power would be used in synchronous motors, and is there any rule for the proportion? (3) What would be the best installation for a flour mill, motors all starting light and load put on by clutches:—that is, what style of motor is best adapted for the work? (4) Advise me fully as to the advantages of a 2200 volt installation in comparison with a 550 volt installation. The service is 60 cycles, three-phase. (5) From a consumer's standpoint, is there any advantage in using synchronous motors to increase the power-factor?

W. J. L. (ALTA)

(1) (a) (b) (c) The efficiencies of squirrel-cage, slip-ring and synchronous motors of the same rating will not be materially different. The power-factors of the squirrel-cage and the slip-ring motor as designed for continuous service, under the same starting conditions, will be approximately the same. The power-factor of a synchronous motor will, of course, be according to the design of the machine. The starting torque of squirrel-cage motors will vary somewhat, according to the speed under consideration; for slow-speed motors it may be as low as 1.25, and for high speed as high as two times full-load torque. The effective starting torque obtained from the squirrel-cage motors is less, on account of starting them through auto-transformers on reduced voltage. The starting torque obtained will be less than the maximum torque of which the motor is capable, as the square of the voltage used is to the square of the line voltage. Starting torque of 2 to 2.5 times full-load torque may be obtained with slip-ring motors, and the full benefit of the motor capabilities of starting torque may be obtained, as the motors are started on full line voltage, with resistance in the secondary, and the resistance is then permanently cut out from the secondary. Synchronous motors may be designed for almost any starting torque up to a little about full-load torque. This type of motor is also started through an autotransformer, and the same relation in regard to the effective starting torque applies to these motors as to the squirrel-cage motors. (2) There is no rule which can be applied to the application of synchronous motors in a plant where a number of induction motors are employed. The capacity of synchronous motors required would be determined by the power-factor obtained from the induction motor installation, and the power-factor desired. Both of these figures will vary greatly in different plants and different situations. (3) In a flour mill it is usually convenient to drive the various machines in groups, in which case the various motors will be of small size, and it is usually convenient to use squirrel-cage motors of standard construction, of the proper characteristics for starting and running the machinery without the use of clutches. By dividing the machinery into groups, and using a number of smaller motors, it is possible to cut down the transmission losses of power in the plant materially, and also to economize on the use of power by shutting down portions of the mill at times when its operation is not required. It is also possible to drive all the machinery in the mill by one large motor. In this case, on account of the large size of the motor, it is preferable to use either a wound-secondary motor, to keep down the current at starting (the use of a squirrel-cage motor would mean several times full-load current drawn from the line at starting, requiring special provision in capacity of the line and transformers feeding the plant), or to use a synchronous motor, starting idle or starting only a portion of the load, and the remainder of the machinery being started by clutches. One large induction motor would give a higher power-factor than a number of smaller motors, and with a synchronous motor it would be possible to obtain 100 percent power-factor. However, one wound-secondary motor would be practically fully loaded most of the time, so that a reasonably high power-factor, possibly even 90 percent, would be obtained. With smaller motors, a lower power-factor would be obtained, although not materially lower. In this case the power-factor of the entire system would be improved by the use of a synchronous motor on some suitable application where the starting torque was light, or a synchronous condenser floating on the line without load. (4) The question of voltage requires a knowledge of the layout of the mill. If a number of smaller motors are desired, necessitating a considerable amount of wiring inside the mill, low voltage should be used on account of the possible danger to the workmen, where if one large motor is used, with but little wiring in the mill, there is no objection to the use of 2200 volts. (5) This could be interpreted as questioning the advantage to a power user of taking precautions to insure a reasonably high power-factor. Considering the motors alone, the power-factor would make no difference in their operation. Low power-factor, however, will mean increase of cable bearing capacity to the plant and in transformers feeding the plant. Motors operating at low power-factor have a direct influence on the capacity of the generating apparatus, and in some cases this is of sufficient value to the central station that they are willing to make a rate concession to those customers who maintain their power-factor above a certain value.

T. E. S.

1297 — Brush Operation — Are some brushes designed to operate with the commutator running towards the "toe" instead of towards the "heel?"

R. B. G. (CALIF.)

Yes; differences in practice in this regard are due to differences in mechanical conditions. Brushes vibrate less in some cases when the direction of the inclination of the brush with respect to the direction of rotation is changed.

F. D. N.

FINANCIAL SECTION

VARIETIES OF BONDS

While the investor, who is seeking as near absolute safety of his investment as possible, must always consider the purchase of bonds, instead of either preferred or common stocks, he must also remember the old adage that "All's not gold that glitters" applies equally as well to bonds as to the metallic kingdom. There are bonds and bonds, and while the generic term "bonds" may be applied to almost all varieties of civic or corporate obligations the investor should always fully understand just what kind of bond he is purchasing and just what priority of lien his security has on the property and earnings of the issuing corporation. In case a bond is offered him at a low price, or on a high yield of income, both meaning the same thing, the investor may usually know that either the bond is not well secured, is a second or third mortgage, or earnings are but slightly more, or perhaps less, than are required for the interest payments. Of course, there are times when a bond may be offered at a low price because of some special circumstances surrounding that particular bond, but these are found but seldom, and in purchasing bonds, as well as other goods, the investor will find that he must pay the higher price when he buys the best.

Bonds are usually divided into two classes, civil and corporation. Under the first class fall such issues as government, state, county, township, municipal and other bonds issued by political subdivisions. These bonds sell at a higher price and yield a lower rate of income than corporation bonds. This is because they are considered more conservative investments with the smallest degree of risk of either interest or principal. Corporation bonds may be divided into three classes. These are transportation bonds, those of railroads, steamship companies, express companies and other corporations engaged in the great transportation industry of the country, although electric street and interurban railway bonds are usually now classed among public utility bonds. The latter include street and interurban railways, natural and artificial gas electric light and power, water supply, water power, telephone and telegraph bonds. The third class of corporation bonds may be made up of such issues as reclamation, timber land, real estate, mining and the bonds of industrial corporations such as steel and iron companies, cotton and other mills and, in fact, bonds issued by any of the many varieties of manufacturing industry.

In connection with the subject of municipal bonds, it might be well to say that the purchaser of a municipal bond should always learn whether it is a direct obligation of the issuing political subdivision or, what is sometimes known as a district bond, a bond issued by a taxing district for improvements and its payment provided for by assessments on the property benefited by the improvement. These bonds are sometimes subjects of dispute and are not as good investments as the bonds issued by authority of the entire municipality and backed by its general credit.

However, at present this discussion will be devoted to corporation bonds, especially to that class denominated "public utility issues," and more particularly to those of electric light and power and electric railway corporations. This class of bonds offers the investor an opportunity for the highest income yield with the largest degree of safety of principal and interest, statistics showing that in this respect they are far ahead of any other class of corporation issues, being comparable, among corporation bonds, only to those of gas and water supply companies.

In recent years natural gas bonds have become quite popular with many investors, and there has been but a low ratio of loss on these issues. One cause of their popularity is that they usually sell on a higher income basis and are of short maturity, often but ten years and with a sinking fund of ten percent a year, so that the entire issue is paid off by their sinking fund by the time of maturity. This provision is made in the case of natural gas bonds because of the nature of the business, it being estimated by public utility men that, by reason of the gradual exhaustion of its gas supply, a natural gas company must provide for the amortization of its investment over a limited period.

Bond nomenclature is of such a nature that it is practically impossible to determine just what degree of priority a certain bond may have from its title. It is

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always well to have a copy of the indenture of the bond which it is desired to purchase or an explanation from the selling house in regard to just the relation that particular bond may bear to the other capital obligations of the company. While not true abroad, it may usually be considered as true in this country, that when an issue is denominated as a "debenture" or as a "debenture bond" it is an unsecured obligation of the issuing corporation or, in other words, that it is the simple promise of the company to pay and is not secured by any tangible property, but only by the credit of the corporation. Sometimes debentures are secured, but this is so seldom that it is not probable that the average investor will ever run across a debenture of the second class. Sometimes debenture income bonds are issued.

Income bonds of a corporation are bonds which, while secured by mortgage on property, are entitled to interest only in case it is earned, and in this regard are but little better than preferred stocks. Failure to pay interest, if it has not been earned, gives no right to take over the property. Some income bonds are cumulative and others non-cumulative. In the case of the former the unpaid interest remains as an obligation of the corporation until paid, while in the latter case no such obligation rests on the company, and the failure to pay the full interest on the bonds puts no claim on the issuing corporation so long as the terms under which the bonds were issued have been observed. Income bonds take precedence over the stocks of a corporation in case of dissolution of the company and, of course, have a prior lien on the income of the corporation to that of the stock.

Many bond salesmen use the terms "assumed" and "guaranteed" almost interchangeably, but the terms must not be confused. Where a corporation acquires another company and merges the corporate identity of the latter into itself the bond is "assumed," as the bonds become the direct obligation of the purchasing company, being "assumed" just as is the mortgage on a house when the title to the property changes. Often, however, the corporation simply purchases the control of the other corporation and the latter does not lose its corporate identity, and in order to strengthen the credit of the purchased company the purchasing corporation "guarantees" the bonds of the latter. The terms of the guarantee may be stamped on the bonds or be included in a supplementary agreement. When the bonds are stamped they are known as "stamped" bonds. While guaranteed bonds are usually considered a high form of investment, it is always well to look carefully after the terms of the guarantee and also the credit of the guaranteeing corporation. Just because the bond has been "guaranteed" is not sufficient to make it a safe investment, as has been proved more than once in the corporation history of the United States. The purchaser of a guaranteed bond should always look, or have looked up, the credit and standing of the guaranteeing corporation.

Secured bonds are of two classes, either secured by mortgage on real property or by the deposit with a trustee of collateral. This collateral may be other bonds, stocks or notes endorsed by officers of the issuing corporation. In purchasing collateral trust bonds it is well to learn just the kind of collateral which has been deposited, whether it is first mortgage bonds of subsidiary companies, other bonds, stocks, notes or other securities. This may always be learned from the selling house. Many purchasers of collateral trust bonds, who have not taken this precaution, have had reason to regret that they did not do so. It is also well to learn just what right the holders of the collateral trust bonds have over the collateral in case of default. Sometimes the collateral is tied up in such a manner that the holder of a collateral trust bond has small liberty of action in case a default occurs. As already said, the name of a bond does not always give full information in regard to the standing of its lien on the mortgaged property, so it is always well to ask the selling house to explain just what priority of lien that particular mortgage has on the property.

"First mortgage" without any qualifying term speaks for itself and may be considered as a first or prior lien on the property mortgaged. "First and refunding" means usually that the bonds were issued to refund an issue already outstanding on the property and that after these bonds are taken up the first and refunding bonds will be a first lien on the property. "Consolidated" usually means that the mortgage has been made on consolidated properties, and when "first" is added to it should mean that the bonds are first mortgage bonds. "General" is usually understood to mean that general mortgage bonds which cover the entire property and are subject to the underlying mortgages which may be on the property. In this connection it should be said that when "underlying" bonds are spoken of, bonds with priority of liens are meant, while "overlying" means that the bonds spoken of are junior or subject to other underlying issues.

It would be much better for the investor if there were a definite nomenclature for bonds, so that the same name would mean the same thing for all bond issues, but as this is not so now, no matter how it may be in the future, the only thing for the careful investor to do is to make full inquiry and learn from the selling house just what the name of the bond which he is investigating really means. He may be certain, however, that when he buys a first mortgage bond under that name with no qualifying adjective that he is getting a real prior lien, for no bond house would dare put out a first mortgage bond as anything else. In the case of income bonds he may also know that he will get his interest if it is earned, and in the case of debenture bonds he may, almost without exception, know that he is getting an unsecured obligation based on the credit of the issuing company and not secured by mortgage either on real property or by collateral.

The investor will find, in the case of natural and artificial gas companies and electric light and power companies and other similar corporations, that their bond nomenclature is much more easy to understand than that of steam railroad bonds. In fact, it has largely been the steam railroads that have been responsible for the confused terminology of bonds. In the many reorganizations of these properties the reorganizing interests were hard put to it to find distinguishing terms for the new securities, and so they coined titles for bonds which really do little to explain just what the bonds really are.

Public utility holding companies are large issuers of collateral trust bonds, because they own, not the physical property of their operated companies, but usually control through ownership of the stocks of the latter. Sometimes the operated companies are leased, but this has not proved successful, and substantially all properties are now taken over by purchase of the actual control of the capital stocks of the operated companies. In issuing their collateral trust obligations the holding companies deposit these stocks with a trustee as security or collateral for their bonds. Sometimes the bonds of the underlying companies are deposited. In the latter case the issuing corporation usually placed the word "mortgage" in the description of the bond as "collateral trust mortgage" bond. Of course, the bond se-

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cured by the deposit of underlying bonds is of a higher grade than one secured by the deposit of stocks alone, but with the high degree of earning power of gas and electric light and power companies on their stocks there is little danger in the stock collateral and, so far as known, no holding company, properly managed, has failed to meet its full obligations on its stock secured collateral trust obligations.

The purchaser of natural, artificial gas, electric light and power or electric railway bonds will usually have but little difficulty in securing full information on these securities. The corporate organization of the majority of them is simple and their bonds are not difficult to understand. The intending investor should first of all learn just what class of bond he is buying, whether first mortgage, collateral trust, income, debenture or some other form. Also, just what rights he might have in case of default, no matter how remote the possibility of this may be, and the earnings of the company, applicable to payment of the interest on this particular class of bond over a period of from three to five years, and thus see whether the margin of safety above interest charges has been growing as it should. It is well also to ask about the sinking fund provisions, although it is becoming quite common now to issue bonds without sinking funds, and whether or not bonds purchased for the sinking funds are bought in on tenders or drawn by lot and retired. In the latter case, the price at which the bonds are to be paid for should be known. In the case of sinking fund bonds retired by lot, it is, of course, possible that a bond might be purchased one year and retired the next through the operation of the sinking fund.

In regard to the price which should be paid for bonds it has already been said that the higher the degree of safety of the investment the higher usually is the price of the bond and the lower the income received on the money invested. In bonds, as in all other matters of business, it is the degree of risk which governs the rate of return. If as near absolute safety as it is possible to secure is wanted this must be paid for, while if the investor is willing to take more of a risk he can secure a larger return for his investment. It is never well for the average investor to pay above the face value of a bond, or, in other words, to purchase a bond at a premium. Many bond houses instruct their bond salesmen not to sell the average investor a bond at a price above par, but to reserve such bonds for large investors, banks or insurance companies. The reason for this is that the average investor does not understand the principles of amortization and, if he bought a bond at, say, five points above par, held it to maturity and received for his $1000 bond $50 less than he paid for it, he would probably want an explanation from the selling house. The bank or insurance company, on the other hand, would have set aside each year a small percentage of the income received on the bond to amortize, or, in other words, to absorb, by the maturity the $50 above face value paid for the $1000 bond, a thing which the average investor would not think of doing.

In regard to figuring the rate of income on a bond, the investor must not use the same method as he would in figuring the income on a stock. In the case of a stock with no maturity the income is "flat" and can be determined simply by dividing the amount per share received each year in income by the price paid per share for the stock, thus giving the percent of annual income yield. In the case of bonds the procedure is much more complicated, and to obtain an income yield on bonds exactly higher mathematics must be employed. Books of bond value having these returns figured out to several decimal points are used by all of the large buyers or sellers of bonds. In computing the rate of return on a bond, not alone must the interest received each year be included, but also the discount (the amount below face value at which the bond was bought), or the premium (the amount above face value which was paid), together with the time which the bond has yet to run to reach its maturity. By a complicated calculation, involving the use of logarithms, the rate of yield is found. Were it not for the bond tables bond houses would be compelled to keep a large staff of trained mathematicians to figure out the income yield of their bonds.

It is impossible to describe in detail all the varieties of bonds which are being offered daily to investors and, so far as possible, we will be glad to answer for our readers any questions they may ask in regard to investments. In the next number of the JOURNAL stocks as investments will be taken up and some of the principles of stock investment explained.

UTAH SECURITIES CORPORATION

Utah Securities Corporation has sold to New York bankers $1 700 000 of the 7 percent preferred stock of Utah Power & Light Company which it held in its treasury. The proceeds of the sale will be used to retire as many of the 10 year, 6 percent notes of Utah Securities Corporation as the amount of $1 700 000 available for purchase of these notes will buy. Some time ago Utah Securities Company sold $3 000 000 of similar stock, the proceeds being used for the retirement of these 10 year notes. Reports from the electric light and power properties of Utah Light & Power Company indicate that the large gains in earnings of the latter part of 1915 are being continued into 1915, and that with any increase of magnitude in the demand for current the company will be compelled to arrange for increased generating and transmission facilities.

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TENNESSEE POWER COMPANY

Tennessee Power Company, controlled by Tennessee Railway, Light & Power Company, which guarantees principal and interest on the $7 250 000 of first mortgage 5 percent bonds of the power company, is now showing much better earnings. These bonds have been selling at a low price because earnings of the company were not enough to cover the bond interest, the deficit being provided for by the holding company and its bankers, but for 1915 the company earned $39 038 above the interest requirements, as compared with a deficit of $138 326 in 1914. The earnings of the company for the first two months of 1916 were also well above the interest requirements, although in the corresponding period of 1915 the interest was not earned. Demand for current on Tennessee Power Company is now in excess of its generating capacity, and a new steam station of 10 000 horse-power is being constructed at Parksville and a new hydroelectric station of 13 000 horse-power is being built at Great Falls. On the completion of these two stations Tennessee Power will have 58 000 horse-power of hydroelectric capacity and 45 000 horse-power of steam generating capacity. In addition, it has a contract with the Chattanooga & Tennessee River Power Company, controlled by the Brady interests, by which the latter company will furnish it 55 000 horse-power of energy as soon as the installation of additional generating units in its hydroelectric station at Hales Bar is completed. Nearly 92 percent of the output of Tennessee Power Company in 1915 was generated in its hydroelectric stations and but 8 percent in steam stations, the increase in total generation over 1914 being 38 percent. The maximum demand on the system in December, 1915, was 62 000 kilowatts, and in December, 1914, 47 600. One cause of small net earnings in 1914 was that steam generation was largely used because of abnormally low water in the streams of Tennessee.

INCREASES IN ELECTRIC POWER BUSINESS

Some of the smaller electric light and power companies of the country are reporting astonishing increases in their earnings due to the heavy increase in the use of electric current. Massillon (Ohio) Gas & Electric Company reported for the 12 months ended February 29, 1916, a gain of 64 percent in gross and of 135 percent in net as compared with the preceding 12 months. Alliance Gas & Power for the same period showed a gain of 26 percent in gross and of 36 percent in net. Trumbull Public Service Company made a gain of 27 percent in gross and 54 percent in net, while the Empire District Electric Company increased its gross 52 percent and its net 44 percent. Bristol Gas & Electric Company reported a gain of 11 percent in gross and of 39 percent in net. The reports of these companies, well scattered over the country, indicate that the electric light and power business is now in the most flourishing condition in its entire history.

RECORD APPLIANCE SALES

The Doherty Organization, which has charge of the operation of the properties of Cities Service Company, reports that its sales of lamp socket electrical appliances for the 12 months ended February 29, 1916, were $802 494, as compared with $506 775 for the preceding 12 months, an increase of $275 719. The net profit on the sales of appliances for the same period was $35 800, as against a loss of $44 500 for the preceding 12 months, or a gain of $80 300 in profits. That the sales of these electrical appliances is steadily increasing is shown by the fact that for February, 1916, sales of the Doherty Organization were $71 670, as compared with $27 930 in February, 1915.

NORTHERN STATES POWER

Northern States Power Company has called for payment, May 1, the $7 210 000 of Consumers Power of Minnesota 20 year, 5 percent bonds due 1929, and the $1 434 500 of 6 percent collateral lien notes of Consumers Power of Minnesota due May 1, 1917. It also has called for payment June 1, 1916, the $5 000 000 5 year, 6 percent collateral lien notes of Northern States Power Company due June 1, 1917, and the $3 000 000 six percent notes of Minneapolis General Electric Company, June 1, 1917. To provide for the retirement of these bonds and notes Northern States Power Company has sold to a syndicate of Chicago and New York bankers its own long-term bonds of sufficient amount to provide not only for the payment of the above securities, but also for other corporate requirements of the company. By this simplification of its financial organization, and also the simplification of its corporate organization now under way, Northern States Power Company will be in position soon to place its common stock on a regular dividend basis.

ALABAMA POWER COMPANY

Alabama Power Company, a subsidiary of Alabama Traction, Light & Power Company, has sold to New York bankers $4 000 000 first mortgage, 30 year, 5 percent bonds, the first issued under an authorized mortgage of $100 000 000. Proceeds of the new issue will be used to retire the $2 000 000 six percent first mortgage bonds now outstanding and for improvements and extensions to its properties. Included in the additions will be a new 30 000 horse-power steam generating station in the heart of the coal fields in the Black Warrior district and the extension of its high-tension transmission lines. The company now owns a 70 000 horse-power hydroelectric station at Lock 12 on the Coosa River, and this is being enlarged to 90 000 horse-power capacity. It also owns a 15 000 horse-power steam generating station at Gadsden, Ala. The new bonds are well protected by the value of the physical property, by restrictions in regard to earnings and by a sinking fund. For the year ended February 29, 1916 earnings of the company applicable to the payment of interest on these new bonds were $607 000, or more than three times the annual interest charges.

WEST PENN TRACTION COMPANY

Through the proceeds of the sale of the $8 000 000 first mortgage bonds of West Penn Power Company, the West Penn Traction Company has paid off and canceled 51 percent of its first mortgage 5 percent bonds, and now has but $5 536 000 of these bonds outstanding. By the purchase and cancellation of the bonds which were put up as collateral for the West Penn Traction three-year 6 percent notes due in 1917 the company now has sufficient funds on hand to provide for the payment of the $6 000 000 of these notes, and they will be called for payment September 1, 1916, at 100 and interest. The retirement of these notes will place the company in position to turn over to the American Water Works & Electric the proportion of its surplus earnings accruing to that company from ownership of stock in West Penn Traction & Water Power Company, the holding corporation for West Penn Traction and West Penn Railways.

ST. JOSEPH RAILWAY, LIGHT, HEAT & POWER

Showing the marked gain which has taken place in the demand for electric light and power, the St. Joseph Railway, Light, Heat & Power Company reports that for January, 1916, its generating stations had an output of 2 484 533 kilowatt-hours as compared with 2 132 902 kilowatt-hours in 1915, while for February, 1916, the output was 2 198,811 kilowatt-hours, as compared with 1 900 247 kilowatt-hours in February, 1915.

TENTATIVE PROGRAM FOR THE CHICAGO N.E.L.A. CONVENTION

A tentative program of the work to be done at the Chicago convention, May 22-26, has been announced by the secretary, Mr. T. C. Martin. At San Francisco, in 1915, the working sessions for various reasons were limited to three days—Tuesday, Wednesday and Thursday—but at Chicago there will be sessions on Friday morning. There are three special features of the program this year. Three sessions are occupied by the new Electric Vehicle Section, and two are devoted to the new Company Section Committee, which is doing splendid work in the development of this branch of Association usefulness. The third item is that the Public Policy meeting will be an executive session, open only to Class A operating companies and their representatives. A more attractive program was never presented to the membership than that which follows:—

TUESDAY, MAY 23

FIRST GENERAL SESSION—10 A. M.—1—Welcome to the City—Mayor Thompson; 2—Address of President Lloyd; 3—Announcements; 4—Report of Committee on Organization of the Industry (Membership)—George Williams; 5—Report of the Secretary—T. C. Martin; 6—Report of Insurance Expert—W. H. Blood, Jr.; 7—Report of Committee on Progress—T. C. Martin; 8—Report on *Question Box*—S. A. Sewall; 9—Report of Committee on Relations with Education Institutions—J. F. Gilchrist; 10—Report of Committee on Company Sections—F. J. Arnold.

FIRST TECHNICAL AND HYDRO-ELECTRIC SESSION—2:30 P. M.—1—Chairman's Address—Holton H. Scott; 2—Report of Committee on Meters—C. G. Durfee; 3—Report of Committees on Electrical Measurements, Values and Terminology—A. E. Kennelly; 4—Paper: *Lightning Protection for Transformers*—D. W. Roper.

FIRST ACCOUNTING SESSION—2:30 P. M.—1—Chairman's Address—H. M. Edwards; 2—Election of Nominating Committee; 3—Report of Executive Committee; 4—Report of Membership Committee—E. J. Allegaert; 5—Report of Committee on Classification of Accounts—William Schmidt, Jr.; 6—Report of Committee on Cost Accounting and Statistics—T. J. Walsh; 7—Report of the Library Committee—Alex. Holme.

FIRST COMMERCIAL SESSION—2:30 P. M. 1—Chairman's Address—J. F. Becker; 2—Report of Committee on Finance—E. A. Edkins; 3—Report of Committee on Membership—H. N. McConnell; 4—Report of Committee on Publications—C. A. Littlefield; 5—Report of Committee on Salesman's Handbook—M. S. Seelman; 6—Report of Committee on Education of Salesmen—F. R. Jenkins; 7—Paper: *The Way to Make a Salesman*—Earl E. Whitehorne; 8—Report of Committee on Merchandising and Recent Development in Electrical Appliances—W. G. Stetson.

SECOND GENERAL AND EXECUTIVE SESSION—8:30 P. M.—1—Report of Committee on Public Policy—W. W. Freeman; 2—Report of Committee on Taxation of Public Utilities—John A. Britton.

WEDNESDAY, MAY 24

SECOND ACCOUNTING SESSION—10 A. M.—1—Report of Committee on Form of Annual Report—C. H. Hodskinson; 2—Report of Committee on Customers' Records—E. J. Fowler; 3—Report of Committee on Purchasing and Storeroom Accounting—H. F. Frasse.

SECOND COMMERCIAL SESSION—10 A. M.—1—Report of Committee on Wiring—R. S. Hale; 2—Report of Committee on Lamps—Frank W. Smith; 3—Report of Committee on Electric Ranges—W. R. Putnam; 4—Election of Committee on Nominations.

THIRD GENERAL AND EXECUTIVE SESSION—10 A. M.—1—Report of Treasurer—W. H. Atkins; 2—Election of Committee on Nominations; 3—Report of Committee on Rate Research — Alex. Dow; 4—Report of Committee on Constitution and By-Laws—R. S. Orr; 5—Report of Committee on Geographic Sections—Louis D. Gibbs; 6—Address: *The Society for Electrical Development*—J. M. Wakeman.

FIRST ELECTRIC VEHICLE SESSION—10 A. M.—1—Address of Chairman—Walter H. Johnson; 2—Report of Secretary—A. Jackson Marshall; 3—Report of Treasurer—H. M. Edwards; 4—Report on Section Activities—Secretary Marshall; 5—Report of Committee on Membership—Joseph D. Israel; 6—Report of Committee on Standardization—E. R. Whitney; 7—Report of Committee on Motion Picture Films—Carl H. Reed; 8—Report of Committee on Traffic and Good Roads—A. H. Manwaring; 9—Report of Committee on Insurance—Day Baker; 10—Election of Nominating Committee.

SECOND TECHNICAL AND HYDRO-ELECTRIC SESSION—2:30 P. M.—1—Report of Committee on Underground Construction—E. B. Meyer; 2—Report of Committee on Overhead Line Construction and Inductive Interference—R. J. McClelland; 3—Report of Committee on Hydro and Transmission Progress—T. C. Martin.

THIRD COMMERCIAL SESSION—2:30 P. M.—1—Report of Power Sales Bureau—C. J. Russell; 2—Paper: *Central Station Service in the Manufacture of Artificial Ice*—C. J. Carlsen; 3—Report of Committee on New Industrial Applications of Electricity—P. Torchio; 4—Report of Industrial Electric Heating Bureau—C. F. Hirshfeld.

SECOND ELECTRIC VEHICLE SESSION—2:30 P. M.—1—Report of Committee on Garages and Rates—George B. Foster; 2—Report of Committee on Legislation—P. D. Wagoner; 3—Report of Committee on Federal and Municipal Transportation — James H. McGraw; 4—Paper: *Industrial Truck Applications*—C. W. Squires; 5—Paper: *Electric Truck Problems and How to Minimize Them*—F. E. Whitney; 6—Paper: *The Relation of Tires to Electric Vehicle Efficiency*—S. N. Norton; 7—Paper: *Greater Garage Service*—Harry Salvat.

THURSDAY, MAY 25

THIRD TECHNICAL AND HYDRO-ELECTRIC SESSION—10 A. M.—1—Report of Committee on Accident Prevention—Martin J. Insull; 2—Report of Committee on Prime Movers—I. E. Moultrop; 3—Report of Committee on Electrical Apparatus—L. L. Elden.

THIRD ACCOUNTING SESSION—10 A. M.—1—Paper: *Correspondence Course in Accounting*—A. L. Holme and J. R. Wildman; 2—Report of Committee on *Question Box*—Edwin A. Barrows; 3—Open Discussion and Experience Meeting; 4—Report of Committee on Nominations; 5—Election and Installation of Officers;—Adjournment.

FOURTH COMMERCIAL SESSION—10 A. M.—1—Report of Lighting Sales Bureau—John G. Learned; 2—Report of Committee on Commercial Aspects of Highway and Municipal Lighting—T. F. Kelly; 3—Report of Committee on Industrial and Yard Lighting—Oliver R. Hogue; 4—Lecture: *Lighting—A By-Product or a Buy Product* (Illustrated)—William A. Durgin.

THIRD ELECTRIC VEHICLE SESSION—10 A. M.—1—Report of Committee on Operating Records—W. P. Kennedy; 2—Report of Committee on Central Station Co-operation—E. S. Mansfield; 3—Paper: *The Exchange Battery System*—P. D. Wagoner; 4—Paper: *Passenger Vehicle Problems and Activities*—E. P. Chalfant; 5—Paper: *Central Station Promotion of Electric Vehicle Use*—W. P. Kennedy; 6—Report of Committee on Nominations; 7—Election and Installation of Officers;—Adjournment.

FOURTH TECHNICAL AND HYDRO-ELECTRIC SESSION—2:30 P. M.—1—Report of Committee on Street Lighting—S. B. Way; 2—Report of Committee on Power Supply for the Electrification of Steam Railroads—Peter Junkersfeld; 3—Paper: *Central Station Electric Systems and Railroad Power*—F. Darlington.

FIFTH COMMERCIAL SESSION, POWER SALES BUREAU—2:30 P. M.—1—Paper: *Temporary Service for Municipal Sub-Service and Other Construction*—C. K. Nichols; 2—Paper: *The Resistance Heater as a Load Builder*—E. F. Collins; 3—Paper: *Electric Furnaces*—R. H. Tillman; 4—Paper: *Electric Welding*—S. R. Dresser; 5—Report of Committee on Competitive Power Sources—E. F. Tweedy.

FIRST COMPANY SECTION SESSION—2:30 P. M.—1—Paper: *The Company Section and the Company*—M. S. Seelman, Jr.; 2—Paper: *Financing Company Sections*—A. L. Atmore; 3—Paper: *Company Section Educational Work*—Douglass Burnett; 4—Paper: *Company Section Entertainment and Recreation*—A. D. Bailey.

FRIDAY, MAY 26

FOURTH GENERAL AND EXECUTIVE SESSION—10 A. M.—1—Awarding Doherty, Williams and Frasse prizes; 2—Report of Nominating Committee; 3—Report of Committee on President's Address; 4—Report of Committee on Memorials; 5—Report of Committee on Resolutions; 6—Election and Installation of Officers;—Adjournment.

SIXTH COMMERCIAL SESSION, LIGHTING SALES BUREAU—10 A. M.—1—Report of Committee on Residence Lighting—Fred H. Scheel; 2—Report of Committee on Stores and Public Buildings—S. B. Burrows; 3—Report of Committee on Electrical Advertising—A. K. King; 4—Election and Installation of Officers;—Adjournment.

SECOND COMPANY SECTION SESSION—10 A. M.—1—Paper: *Employees' Activities: Should They ALL Be Under the Auspices of the N.E.L.A. Company Section?*—J. D. Israel; 2—Formation and Methods of Conducting Company Sections—E. C. Stone; 3—Suggestions by Committee on Company Sections—F. J. Arnold;—Adjournment.

ELECTRIC VEHICLE ASSOCIATION BECOMES ELECTRIC VEHICLE SECTION OF THE N.E.L.A.

The Electric Vehicle Association has formally accepted the invitation of the N.E.L.A. Association to affiliate with the latter as its Electric Vehicle Section. Their headquarters will be transferred to the N.E.L.A. offices, with Mr. A. J. Marshall as secretary of the new Association section.

PERSONALS

Mr. Clement F. Street, formerly of the East Pittsburgh sales department of the Westinghouse Electric & Mfg. Company, and at present vice president of the Locomotive Stoker Company, has been awarded the John Scott legacy and premium by the Franklin Institute for the Street locomotive stoker.

Mr. Henry M. Brinckerhoff, of the consulting engineering firm of Barclay, Parsons & Klapp, has been appointed chief engineer of the Chicago Traction and Subway Commission, recently organized to prepare a report on the consolidation of surface and elevated lines and on subways.

Mr. E. C. Geither, formerly of the New York district office of the Westinghouse Electric & Mfg. Company, and later of the Ellcon Company, New York City, is now with the Ingersoll-Rand Company and has recently been appointed sales manager of their New York office. He will also have charge of the sales of the A. S. Cameron Pump Works in the New York City territory.

Mr. E. A. Cousins, engineer in charge of the New York Automobile Service Department of the Westinghouse Electric & Mfg. Company, has resigned to become general superintendent of the Daniels Motor Car Company, Reading, Pa.

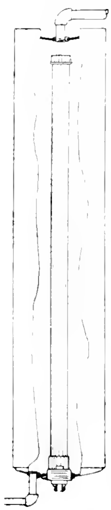
Mr. H. O. Swoboda, consulting electrical engineer, Empire Building, Pittsburgh, Pa., has been retained by the Borough of New Brighton, Pa., for the purpose of planning a new street lighting system.

Mr. D. W. Beldon, who has been in charge of the El Paso district office of the Westinghouse Electric & Mfg. Company since it was opened in 1909, has resigned to become direct representative of the Westinghouse Export Company at Valparaiso, Chile, South America.

Mr. Stanleigh O. Kelley will take a position on May 8 with the Public Service Company of New Jersey as power representative in their Camden district. Mr. Kelley graduated from Clemson College in 1910. Leaving college he spent two years in the apprentice course of the Westinghouse Electric & Mfg. Company. He then took a position with the Birmingham Railway, Light & Power Company, doing special work in the application of electricity to coal mines, brick and tile plants and other industries. Two years later he accepted a position as power and light salesman with the Cleveland Electric Illuminating Company.

THE LEE ELECTRIC WATER HEATER

The unity load factor so keenly sought by central stations is one of the primary talking points in the distribution of the Lee electric water heater recently placed upon the market. The objectionable load feature and operating cost of the instantaneous water heater has been entirely overcome by the advent of this continuous use domestic appliance. The most popular sizes in use are the single heat elements of 500 and 750 watts, although the line is completed with 1500 and 2000 watt sizes with a three-heat control feature. Inasmuch as these are insert water heaters and are 100 percent efficient, the most desirable results are obtained. All the energy supplied to the unit is dissipated in the water in the form of heat without loss. A number of tests made by various laboratories, among them the Lewis Institute of Chicago, show that water can be had at various hours ranging in temperature from 110 to 185 degrees: or approximately 45 gallons every twenty-four hours at a temperature of 115 degrees (bath temperature), more than enough for the average household. The construction of the water heater is like a pipe or rod, $1\frac{1}{4}$ inches in diameter, $50\frac{1}{2}$ inches long, and threaded for one inch at the top, so that it is only necessary to insert this unit through the standard opening in the top of any ordinary range tank. This rod is filled with an insulating non-oxidizing fluid in which is submerged the open resistance coil or heating element, a construction similar to that of Lee electric radiators. The Lee Electric Radiator Company, Peoples Gas Building, Chicago, Ill., furnish this device complete with a special heat-resisting cover for a tank.



NEW CATALOG OF POLE LINE HARDWARE

Hubbard & Co., Pittsburgh, Pa., have issued a complete catalog of their standard pole line hardware and specialties. This book, in its completeness and thorough method of treatment, well constitutes an encyclopedia of buying materials. In listing the articles a photograph of the article has been furnished, together with an adequate description and table of sizes and dimensions. Wherever needed, use has been made of photographs and detailed drawings showing the way the materials are used in actual practice. The book contains 610 illustrations and 200 pages, $8\frac{1}{2}$ by 10 inches, and is printed on a suede finish offset paper which is particularly agreeable to the eyes. It has a dark green, flexible paper cover and can conveniently be rolled up and carried in one's pocket. The book is divided into sixteen sections, in each of which material is grouped according to the purpose for which it is used, as follows:—Pole work material, guying material; cross-arms, pins and fittings; high-tension arms and fixtures; pole top pins and fixtures; secondary distribution fixtures; transformer mounting material; Pierce service wire brackets; hammer drills and expansion bolts; street lamp suspension devices; electric railway overhead and third-rail material; cable suspension material, underground cable material, telephone and telegraph wiring, line and track construction tools and Bates expanded steel poles. A copy will be sent free on request.

LARGE TURBINE ORDER

Among the number of orders for turbines of large capacity received by the Westinghouse Electric & Mfg. Company is an order from the Narragansett Electric & Light Company, of South Providence, R. I., for one 45 000 kw turbo-generator unit complete with condensers and all auxiliary apparatus. The Westinghouse Company has also sold one 2500 kw synchronous booster rotary converter with transformers and switchboard equipment to the same company.

The Buffalo General Electric Company has purchased from the Westinghouse Electric & Mfg. Company, of East Pittsburgh, Pa., complete switching equipment to control three 20 000 kw turbo-generator units and auxiliary apparatus located in their river station at Buffalo, N. Y.

The Electric Storage Battery Company, of Philadelphia, manufacturer of the "Exide" battery, the "Chloride Accumulator," "Tudor Accumulator" and the "Ironclad-Exide" battery, announces a change in the handling of its Pacific coast business, which took effect January 1. Due to changes in the organization of Pierson, Roeding & Co., who have acted as the Electric Storage Battery Company's sales agents on the coast since 1910, the battery company will hereafter conduct its business on the coast through Mr. George R. Murphy, with offices in the Rialto Building, 118 New Montgomery street, San Francisco. The exide battery depot which was opened in San Francisco a number of years ago, and where a large amount of stock is carried, will give Mr. Murphy a base of supplies that will insure prompt shipments of batteries and parts. The Electric Storage Battery Company's business on the coast has been very satisfactory in batteries for use in electric commercial and pleasure vehicles, mine locomotives, industrial trucks, for automobile starting and lighting service and in other fields of storage battery application.

The Westinghouse Lamp Company has issued the fifth of a series of booklets for lamp salesmen, the present one being entitled "Selling Mazda Lamps and Better Light." It is made up of short selling talks to different types of customers, such as Mrs. Jones, a home-owner using gas, to a store-owner using gas arcs, to a manager using carbon arc lamps, to a proprietor using metalized filament lamps, to an industrial plant manager using carbon incandescent lamps, etc. Copies of this booklet No. 5 will be sent on request to the Westinghouse Lamp Company, 1261 Broadway, New York City.

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Recent Central Station Developments

The remarkable increases in the efficiency of illuminants recently achieved have become widely known. In Chicago, for instance, one dollar will now buy nearly 15 000 candle-hours as compared with about 1100 candle-hours with the early carbon lamps. In other words, over thirteen times more light can now be secured per dollar than was the case in the early nineties. This involves not only increased lighting efficiency, but also a rate decrease which has resulted from improved methods of power generation. In the latter field enormous strides are now being made, similar in their rapidity to those immediately following the advent of the tungsten lamp. In the present case it is the steam turbine generator and steam generating equipment that are making phenomenal progress. Mr. J. F. Johnson, in this issue, states that in 1913 one turbine of 15 000 and one of 20 000 kilowatts capacity were placed in operation. A short time ago the Interborough Rapid Transit Company contracted for a 60 000 kilowatt unit, a truly remarkable increase in three years.

Viewed from the economic standpoint, the prime object aimed at by the power company is the greatest efficiency from the coal pile to the consumer. With the steam turbine units and boilers already in operation, great economies have been effected in coal consumption. An item which should be of interest to the conservationist is the statement made by Mr. Junkersfeld, in this issue, that the coal rate of the Commonwealth Edison Company, of Chicago, has been reduced since 1903 to such an extent that, on the basis of the rate for 1915, a total of over two and one-half million tons of coal per year is being saved due to improvements in the art of power generation.

The tremendous increase in turbine capacities and total efficiencies have naturally led to the question as to where is the limit. One very definite limit is that of the temperature at which boilers and turbines can be operated, and the present limit now recognized is 700 degrees F. At present boilers are under construction to be operated at 350 lbs. (gage) pressure with 200 degrees superheat. A pressure of 200-250 lbs, with 150 degrees superheat may be said to represent standard practice in recent high-grade installations. One of the large boiler manufacturers states that, if there is sufficient demand, boilers for 500-600 lbs. pressure with steam superheated to 700 degrees F. can be supplied. In fact, they give the impression that they can take care of their end of the problem if other builders will do as well. In this connection, one steam turbine builder advises that they are now prepared to build turbines for steam pressures up to 500 lbs. An idea may be had as to the importance of these developments when it is realized that with 600 lbs. steam superheated to 600 degrees F. with a 29 inch vacuum there is theoretically an increase in efficiency of 13.4 percent over the efficiency obtainable with the same vacuum and temperature with steam at 200 lbs. Such large increases in efficiency, together with improvements in boiler and furnace construction, and likewise in methods of operation, mean that much greater output can be secured from a given size of equipment.

Steam condenser development is also keeping pace with turbine and boiler progress, and the theoretical limit is being closely approached. The Philadelphia Electric Company, for instance, reports that with a load of 30 000 kilowatts on the turbine they have had no difficulty in maintaining a vacuum of 29.4 in. (with barometer at 30 inches). In another case a jet condenser for a 45 000 kw turbine is being used with highly satisfactory results. Until quite recently it was not considered feasible to use jet condensers in such large capacities.

All of these developments relate to power house operation. There remains the problems of distribution and disposition of power. In the latter field especially, such items as continuity of service, load factor, diversity factor, density of load, etc., are being given careful attention, all of which have an important influence on the ultimate cost of power to the consumer. The various committees of the National Electric Light Association are doing an important work by keeping the membership in touch with important developments in all branches of power development work. As committees they can secure and analyze data both from member companies and from manufacturing concerns in a much more comprehensive manner than is feasible for the ordinary central station organization.

A. H. McIntire

Public Utility Problems

In an article in this issue of the Journal, Mr. Junkersfeld interestingly describes certain developments and fundamental facts of the central station industry, which are particularly relevant in connection with the presentation of its problems to the public. Through dissemination of intelligence of this kind, the central stations as a whole are benefited, not only directly by acquiring a better appreciation of their own problems, but also, and in no small degree, as a result of the sympathetic understanding developed on the part of their patrons and the public in general. There are three matters standing out in more or less bold relief on which users of electric service should be reasonably well informed:—(a) *The important position of the utilities* as a factor of our national wealth and development, whereby community welfare is advanced; (b) *the ele-*

ments distinguishing the costs of various services and establishing the basis of classification; (c) *the endeavors made by the utilities in the routine of their business to provide for the accommodation and convenience of their customers,* not only as pertains to the present conditions, but to future situations as well.

The aggregate investment in public utilities is surprisingly large when compared with the nation's total wealth. The measure of economy realized through our public utility enterprises has been correspondingly large, and consequently the country's resources are thus being conserved. In the one locality discussed, enormous savings in fuel have been effected and, in a similar way, capital and labor have been most efficiently employed. Results of such magnitude as set forth by the author could not have been obtained unless the compensation for the different services rendered had been fairly proportioned to the character of the demand and the expense each class of service involved. The entire business manifestly is fraught with varied problems of an engineering, of a commercial and of an executive nature. In order that the numerous potential possibilities of the utility may materialize, its plans must contemplate the future adequately, and comprise a comprehensive and economic scheme of development; the load must be increased and intensified; and there must be maintained a policy encompassing all reasonable standards and refinements of the service which the patron should enjoy.

An industrial institution, no matter how well conceived and conducted, is often underestimated in value and importance unless all the benefits issuing therefrom are properly appreciated by its patrons. Where a real understanding does not exist, suspicion, distrust and antagonism are liable to ensue, such as is true in all social, political and industrial realms. Remove practically every vestige of mystery, and usually confidence will be won. Consequently the most effective weapon of defense of private property devoted to public use is in the revealing of the true function and the very fabric of the institution in a way that appeals to the intelligence of the general public. The article on "Electric Service Problems and Possibilities" is an excellent example of the carrying out of these principles in a vivid and substantial manner.

EDWIN D. DREYFUS

The Hotel as a Central Station Prospect

The average individual does not think of a hotel as a manufacturing enterprise: and the wide variety of its power requirements and the aggregate capacity of its power apparatus are, on first impression, almost startling. One is not ordinarily liable to connect washing his hands in a hotel with big motor-driven pumps in the basement; nor the clinking of ice in his drinking water with a complete refrigerating plant located in the same building; nor the complete absence from the dining-rooms of the odors produced by cooking, with huge ventilating fans just under the roof. Yet these power devices and many others of a similar nature are absolutely essential to providing the highest type of hotel service.

A power consumption of over 3 600 000 kilowatt-hours per annum, with a five-minute maximum demand of 1000 kilowatts, representing a load factor of over 40 percent, certainly forms a tempting bait to dangle before the eyes of a central station commercial man. It is a load which, on account of its magnitude and great uniformity, warrants a low net rate, and is able to earn such a rate on the standard demand schedules or sliding rates which are in use by practically all of the larger central station companies. A load of such characteristics will also prove of no small interest to the isolated plant salesman, who is equally interested and is equally able to quote advantageous terms for a uniform power consumption at a high load factor. And, when it is accompanied with a requirement for over 75 000 000 pounds of high and low pressure steam per year, as is the case with the William Penn Hotel, which was recently opened in Pittsburgh, the central station man is apt to find he has met a foeman worthy of his steel.

A large modern hotel, by reason of the features mentioned above, forms an almost ideal situation for the successful operation of a private power plant. When an institution of such large and complex power requirements finds it advantageous to make use of central station power throughout, it would seem that the days of the relatively small isolated plant within the territory covered by a large central station are almost numbered. For this reason the decision of the William Penn Hotel (which is described in this issue) to purchase all their steam and their electricity for both light and power, is especially significant.

In addition to the direct benefits accruing to the central station from such a load, the psychologic effect on the architects, engineers and owners of other large buildings in the city is considerable. Pittsburgh is at present passing through an era of construction of large buildings, several of which are being erected in the immediate vicinity of the William Penn Hotel, all of which are expected to purchase their electricity from the local central station. Undoubtedly the question of power requirements for each of these buildings will be or has been figured on its individual merits. But the example of the William Penn must have some influence, even in these instances, and with smaller installations should prove of great value to the central station. The Duquesne Light Company is to be congratulated on having demonstrated to the city of Pittsburgh its ability to furnish satisfactory service to meet the most rigid requirements.

CHAS. R. RIKER

The Work of the National Electric Light Association

E. W. Lloyd
President,
National Electric Light Association

During the year the National Electric Light Association has continued its usual activities for the general good of the industry. The Association has been growing at a very rapid rate, as is evidenced by the fact that we have some five hundred men working on fifty committees, who will present at the convention, to be held at the Congress and Auditorium Hotels, Chicago, the result of their deliberations and conclusions. The large amount of work which has been put on the various reports and papers, and their great value to central station men, are indications of the high class of men we have been able to interest in our work.

The Association has expanded its activities considerably. The affiliation of the Electric Vehicle Association has added quite a number of members to our lists and the Section is in a thriving condition, as is evidenced by the fact that they will have four sessions at the coming convention, with over a dozen reports and papers.

The Industrial Electric Heating Association has also come into our ranks, and they will have several important reports for the convention which will be presented during the sessions of the Commercial Section.

Edward William Lloyd

The Association, in addition to these two new affiliations, has divided itself into four parts, as follows:—Technical and Hydroelectric, Accounting, Commercial, Manufacturers. The first three of these Sections are in full working order and have chairmen, vice-chairmen and executive committees. The Manufacturers Section has been authorized and is merely waiting on the working out of the details before starting its activities.

Our Geographical Sections are ten in all, including our sister society, the Canadian Electrical Association. The Geographical Sections committee this year has produced a report which should be of great interest to the membership, for the reason that it points out the means whereby the entire country can be divided into Geographical Sections, thereby strengthening the Association materially. It seems to me that the future will show a decided tendency towards the development of Geographic Sections through which all local matters can be handled, leaving the broader questions to the parent body.

The convention promises to be very interesting. The program is large, consisting of 23 sessions in four days, making it necessary at times to stage four parallel sessions. The reports of particular interest to Class "B" members will be those to be presented in the Company Sections sessions, of which there will be two, with seven or eight papers. The present activities of the Association should be of particular interest to Class "B" members. Work is going on that will be of material benefit in their education. The reports and papers contain much data that the employe in the central station business cannot get elsewhere. In addition to these, courses are being started in the various sections for the education of the men in their particular part of the business.

One of the things that stands out in the present administration year is the growth of the correspondence salesmanship course, which now has over 1000 members enrolled. It seems probable that the next year will show other sections having equivalent developments in the educational line, similar to that of the Commercial Section. The activities of our General Educational Committee have been important in arousing the interest of large universities in our educational propaganda, and also in interesting the graduates of technical universities in the central station business. The growth of the business demands high-grade young men for the lower positions, so that the future will provide men of sufficient caliber to carry on the business successfully.

We expect to have at the convention a very comprehensive exhibit by our manufacturing members. The Auditorium Theater has been secured and the exhibition

promises to be one of very high caliber. The surroundings will be ideal.

During the winter our Public Policy Committee has been active in the interests of its members, and on February 16 and 17 called a conference of Class "A" members in New York to discuss matters of extreme importance to the industry. Out of this conference we expect to enlarge the activities of the Association to provide help for member companies along any lines that may develop. The advent of commission regulation has demanded more of the companies in the way of information on valuation and regulation, as well as rate-making, and the result of this was a conference on "Valuation," April 10-11, in New York, attended by Class "A" members and engineers to discuss the desirability of more definite terminology in connection with valuation. These two conferences will undoubtedly result ultimately in great good to the central station business.

The New Electrical Vehicle Section of the N.E.L.A.

Walter H. Johnson,
Chairman,
Electric Vehicle Section, N.E.L.A.

When, in the summer of 1910, it was decided by some of the leaders in the electric industry that it would be well to form the Electric Vehicle Association of America, the idea principally in mind was co-operation, that is, the co-operation of all those interests relating to the manufacture and use of electric storage battery cars or vehicles. The scope was broad and liberal in order to secure the membership not only of manufacturers of vehicles and central stations, but also manufacturers of batteries, tires, motors, controllers, etc., users, owners, students of transportation and employes of the larger and more influential member companies.

Walter H. Johnson

Under the strong leadership of Mr. William H. Blood, Jr., Mr. Arthur Williams, Mr. Frank H. Smith, Mr. John F. Gilchrist and others it proved a success from the start, and much work was done and many papers written which aided materially in unifying the standards and methods of the manufacturers and electricity supply companies. There was also started a movement to collect records of the users of trucks and fleets of trucks, so that exact data might be available for the salesmen of both manufacturers and central stations.

During the fourth year of its existence the detail labor of the executive office became so onerous that it was decided to employ a paid secretary and establish headquarters in New York City. Under the new conditions, the fame and activities of the association spread to all parts of the world. Many local branches or sections were formed and the annual conventions grew from one-day affairs to three days of concentrated business. During all this time co-operation between central stations and vehicle manufacturers was constantly emphasized and pushed. Some of the public utilities established garages and service stations and some took agencies for selling the cars.

During the sixth convention, last fall, President E. W. Lloyd sounded an optimistic note anent consolidation with the National Electric Light Association, because, as he put it, so much of the work and interest was along similar lines to the activities of that body. The suggestion was taken up with much favor, and on March 10 of this year the amalgamation was accomplished by bringing in the Vehicle Association as the Electric Vehicle Section of the National Electric Light Association.

Starting with a membership of less than one hundred, the Electric Vehicle Association had grown to over one thousand. And now, instead of having forty-five central station members, it will be in touch with six thousand. It is thought that this will prove of great advantage in popularizing the electric truck and engendering a greater interest and closer acquaintance on the part of a larger number of central station managers and employes than was before possible.

The papers prepared for this convention are intended particularly to put before all the members of the National Electric Light Association the electric vehicle in its present condition of improvement and to show how eminently it is fitted for transportation work; the large interest which all central stations should have in its adoption; and how by co-operation on an extended scale the electric vehicle will be unexcelled as a revenue producer. The exhibition committee has been most generous in apportioning a space for the use of electric vehicle manufacturers and the manufacturers of accessories. The hearty co-operation of all the officers of the National Electric Light Association leads me to confidently predict a most successful convention and gives further assurance, if that were needed, that the good judgment of the members in affiliating with the National Electric Light Association, as a section, will be fully confirmed.

Universal Electricity Supply*

SAMUEL INSULL,
President,
Commonwealth Edison Company

PERHAPS it would be more fitting if I should address myself to the subject that has been assigned to me at one of your regular technical meetings rather than at an annual festive occasion like this. The topic on which I am to speak, namely, the question of universal electricity supply, relates to the difficulties or problems with which you as manufacturers have to deal every day in the week. It is the question of keeping the dollar invested—invested in one branch of the manufacturing business—steadily employed all the time. It is the question of how to produce and to distribute and sell energy at the lowest possible cost to the producer and at the lowest possible cost to the user. Therefore, it is a dry subject, and one, as I have said, hardly suited to a festive occasion.

Moreover, I feel some hesitation—hesitation that I always give expression to if I am appearing before an engineering body—from another cause. I have not had the advantage of an engineer's training. My engineering education has been gained in the College of Experience, and not, unfortunately for me, as I have felt on many occasions, in one of the great technical institutions which, as a whole, have done so much to further the technical training of men, leading to the technical experience of such a body as is represented here this evening.

THE WORK OF WESTINGHOUSE AND DE FERRANTI

In the early days of the production and distribution of electrical energy we were obliged necessarily to confine our undertakings to relatively small areas. The form of electrical energy which we produced was of such a character that, owing to the limitations of the translating devices then available, it did not lend itself to the high pressures which are absolutely necessary for economical distribution over large areas.

We owe to a townsman of yours (a townsman by adoption), not so much as an inventor but as an enterpriser, the early introduction into this country of the alternating-current system of electrical production and distribution. I refer to my lamented friend, Mr. George Westinghouse, who was far-sighted enough to see that, with the development of the manufacturing business of the country, it would be necessary to produce electrical energy in such form as would allow of its being transmitted at relatively low cost over great distances.

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About the time that Mr. Westinghouse introduced the inventions relating to alternating-current production and distribution, a young Englishman by the name of de Ferranti conceived the idea of massing electrical production. He established his generating station at a point on the River Thames below the fixed bridges of London, where he could, without second handling, obtain coal from the mines in the north of England. The fuel was shipped to London in steamships that could go right up to the dock of his generating station. The first long-distance transmission line (that is, long for those days), probably eight or ten miles long, conveyed energy from the Deptford station, erected by Mr. de Ferranti, to the West End of London. That was the first effective effort to attain long-distance transmission. We would think that distance today of very little significance; a point eight or ten miles distant is now practically next door to the generating station.

ELECTRICAL DISTRIBUTION OVER LARGE AREAS

At the time that Mr. de Ferranti first projected his scheme (1889) eight or ten miles was considered a tremendous distance to transmit energy in the form of electricity. The engineer of the Deptford station and transmission was probably ten or fifteen years ahead of his time, or rather ahead of the time when it became possible to bring such a scheme to a financial success. Over twenty years after, when Mr. de Ferranti was president of the (British) Institution of Electrical Engineers, he sketched out in his presidential address a scheme of electrical generation and distribution to cover the greater part of England, certainly that portion of England in which manufacturing is most dense. The plan outlined provided for the generation of energy at the mouth of the coal mines and its transmission practically over the whole area extending from the east coast of England to the coast of Wales.

In this country probably one of the greatest exponents of the same idea is Professor C. P. Steinmetz, the head of the Research Laboratory of the General Electric Company at Schenectady. In some of his public addresses Professor Steinmetz has referred to the possibilities of electrical distribution over large areas, comparing the great transmission lines that must exist in the densely settled portion of the country to the great trunk lines of the railroads. He has described the possibilities of those great transmission lines, supplying them from generating stations, whether those stations have as their prime movers steam engines or steam turbines, or whether they may possibly have the advantage

of hydroelectric plants where water-powers can be developed with economy.

REMARKABLE IMPROVEMENT IN PRIME-MOVER EFFICIENCY

The great progress that has been made in the efficiency of prime movers from the time of the introduction of the steam turbine, relatively but a few years ago, is a very important factor in connection with this development. Energy can now be produced from prime movers having a capacity as great as from 40 000 to 50 000 horse-power. It is quite within the range of possibility that within a few years we shall be using very much larger sizes. Indeed, I fully expect within my own day to see prime movers having a capacity of from 75 000 to 100 000 horse-power produced from electric generators on one shaft.

The essentials necessary for distribution over wide areas are prime movers of very high efficiency, such as I have spoken of, alternating-current transformers of high efficiency, and transmission lines of very high capacity. The improvement in the efficiency of prime movers in the last few years has been upwards of 35 percent; and I am strongly of the opinion that in the next few years, probably by the adoption of very much higher steam pressures, we shall obtain still greater improvement.

It is not at all beyond the range of possibility that eventually, and indeed, in our own day, we shall be operating steam turbines with the aid of boilers running as high as 1000 pounds steam pressure. There should not be any great obstacle to the achievement of the efficiency that would come as a result. It would seem to me that this is a good deal nearer today, relatively speaking, than the steam turbine was not so many years ago, when we depended on cruder forms and less efficient forms of prime movers.

ELECTRIC SERVICE IN LONDON AND CHICAGO COMPARED

To give you some idea of what can be done by massing production and distribution, I will quote from some figures that I am fond of using, making a comparison between the output of electrical energy in the city of Chicago with 2 500 000 people and in the county of London with about 7 750 000 people.

The electricity supply business in the county of London, owing to the condition of the laws there, is operated in a manner exactly opposite to that which is practiced in most of the large industrial centers in this country. I think that there are 63 or 64 different electricity supply undertakings within the area of the county of London, while within the city of Chicago there is one undertaking. The maximum demand in Chicago on the central station system of the city is 338 000 kilowatts. The maximum demand in the county of London is 225 000 kilowatts. The kilowatt-hours generated in the city of Chicago in 1915 were 1 200 000 000. The kilowatt-hours generated in the county of London in the same year were estimated at 571 000 000.

As I have stated, the population of Chicago is about two millions and a half, and that of London is well toward eight millions. We generate in Chicago 500 kilowatt-hours per capita per annum, and in London they generate 74 kilowatt-hours per capita per annum. The cause of this great difference is, of course, the selling price. We manage to distribute and sell the energy that we produce in Chicago for just about the average cost of the energy generated in London; that is, the price that we obtain, which is comparable with the cost in London, has to give us a return on our investment, taking care of the necessary interest and depreciation, while in London they have to earn the sum necessary for profit, interest and depreciation above our selling price.

UTILIZING THE DIVERSITY OF DEMAND

Within the last few years we have had an investigation in the city of Chicago which has led to a report being made by a commission of "Investigation on Smoke Abatement and Electrification of Railway Terminals." This report sets forth among other things some data upon the question of the electrification of steam railroads within what the commission called the "Chicago area." I do not propose to refer to the figures of that report with any idea of advocating the electrification of steam railroads. That is a question that the steam railroads themselves have to settle in their own way and at their own time. But the information contained in that report has quite an important bearing on the question of the centralization of the production of energy and the economics of the production of energy.

As I have told you, the maximum demand on our central stations in Chicago is 338 000 kilowatts. If the steam railroads within the "Chicago area" were electrified, their maximum demand for power would be 125 000 kilowatts. All the energy now produced by owners of individual power plants in this area amounts to about 264 000 kilowatts. If this amount is added to the two preceding figures to get the total power requirements in the area with the steam railroads electrified, the total amount would be 727 000 kilowatts.

The energy demands of these different classes of requirements are so diversified that if you analyze these figures still further you will find that the coincident demand for all these various purposes is only 577 000 kilowatts. Thus, there is a difference between the maximum demand of these requirements, considered separately, and the maximum coincident demand of all of them considered together with their energies supplied from one source. This difference in demand would be 150 000 kilowatts.

TREMENDOUS SAVING IN FUEL POSSIBLE

What does this saving of energy by utilizing diversity of demand mean in relation to the saving of fuel? If all the energy required in the "Chicago area" for the purposes stated was produced from one source, the fuel saving alone would amount to 6 000 000 tons of coal a year, to say nothing of the savings that would be brought about by lower operating expenses and lower investment by taking advantage of the great difference between the

collective demand of the industries considered separately and their coincident demand.

I have carried these figures further, applying the principle to the whole country. I do not mean for one moment to suggest that it is possible to have one great system for the production of electrical energy and its distribution applicable to the whole country. But taking the figures given in the United States Census Reports and using those figures in connection with the figures of the Smoke Abatement Commission of Chicago, one is enabled to arrive at some idea of the savings that can be effected if the energy requirements of the country are massed in the districts in which there is great density of population, great density of manufacturing and great density of transportation.

I will not burden you with the details of the figures; but if the energy required for ordinary present central station purposes, electric railways, steam railways (if electrified), manufacturers, mines and quarries, ice-making, town water pumping, drainage, farm power and electric vehicles—if, say, this production and distribution could be massed in the densely populated districts of Pennsylvania, or in the densely populated districts of Illinois, or in the densely populated districts of New York state, or in any of the densely populated states of the Atlantic seaboard—the diversity between the aggregate individual demand and the coincident demand would be so great that it seems almost hopeless to attempt to calculate it.

GREAT OPPORTUNITIES NOW GOING TO WASTE

Take together all those industries I have named, looking forward relatively a few years to, say, 1925, these businesses will require in the individual aggregate about 68 000 000 horse-power. Massing them in each separate territory, as far as it is possible to mass them and come within areas of economic distribution, and the saving would be upwards of 20 000 000 horse-power. And if you represent that saving in the saving of fuel alone, this saving, based upon an estimated fair average price for coal the country over of $2.50 a ton in 1925, would amount annually to $823 000 000.

Let us transfer our attention from the nation to local communities. I have in mind a community not so very far from Pittsburgh, where the business of electrical generation and distribution in the densely settled portion is conducted by one interest, while in the area outside of the municipal limits this business is conducted by another interest.

Outside of the city the maximum demand for energy comes in the morning; inside of the city the maximum demand for energy comes in the afternoon. The institutions that operate the electricity supply business outside of the city have idle plant during the hours of the day when the institutions producing energy inside of the city have their maximum demand, and the city institution has an idle plant when the institutions producing the energy outside of the city have the greatest demand on them for power. Or, to use a hydroelectric expression, the city lets the water run over the dam in the morning and the country lets the water run over the dam in the afternoon.

That sort of thing is going on all over the country. It is an economical absurdity. It is a waste of capital. It is a tying-up of money that is entirely unnecessary. It leads to greater operating cost and, consequently, to greater selling price to the user.

WHAT CHEAP ENERGY MEANS

If you will take the duplication of investment and the excessive operating expenses which come from the situation which I have just described, and add the two together, the total investment loss in and around the community to which I refer, and which has a population not any larger than that of Pittsburgh and the surrounding territory, is $6 000 000.

This is a subject in which all you people as manufacturers, and, indeed, all the manufacturers of this country, are vitally interested. In discussing it I am open to the charge that I am acting as my own salesman; but I am pleading for the cause in which my business life is spent. After all, what we are all after is to get the greatest possible use out of a given amount of capital. If we, by pursuing one business policy or another, can increase or decrease the cost of production of all manufacturing businesses where the cost of energy is an important element of total cost, we are certainly discussing a subject not merely of local interest and not merely of interest to one individual in particular, but a subject which is of great interest to all of us, whatever may be the line of business that we are following.

Cheap energy means lower cost to the manufacturer; it means lower cost to the transportation company, and that is again reflected in lower cost of rates of transportation or else in increased profits to the transportation companies.

THE BENEFIT TO SOCIETY

The possibility of obtaining cheap energy not only in centers of population, but in country districts, has a great bearing upon the social life of our people. The possibility of the workman being able to obtain employment away from centers of population, owing to the production of cheap energy in country districts, has an important bearing upon the physique of the younger generation. I know of no subject, except possibly the subject of transportation, that has so much to do with the well-being of the people as a whole as the production and distribution of cheap energy to all classes of our population, and to all communities, whether they be large or small. Cheap energy can be achieved by the massing of production and by the massing of distribution by means of high-tension transmission lines. This massing of production and distribution should enable us to carry energy into all parts of the country at such a price as would enable the manufacturers, alike in the country community and in the great centers of population, to compete on an equal basis.

The Central Station as a Factor in Industrial Development

R. S. Orr
General Manager,
Duquesne Light Company, Pittsburgh

THE central station is a vital factor in industrial development. Manufacturers have been slow to appreciate this fact, but the sudden and urgent demands for extra power, arising from the present unusual amount of business, which has taxed plant-producing capacity and denied time for necessary extensions, have forced home lessons that assure a splendid future for centralized power service. The central station has met this emergency in a way that has opened the eyes of the industrial world to the existence of an elastic power that is vital to future industrial growth. The central station has long craved the chance to teach this lesson.

Robert S. Orr

One of the problems of the central station has been to convince the manufacturer that centralized power generation offers an elasticity, a dependability and an economy of operation not possible with an isolated plant. The manufacturer has been slow to inspect his power cost sheets with the same close scrutiny devoted to those of the finished products of his plant. The result is that many industries are submitting to wasteful power generation oblivious to the fact that a new factor has been developed to save them both money and annoyance. One of the few blessings yielded by the European war is the awakening that has come to the manufacturing world, overwhelmed with profitable and urgent contracts. Almost every manufacturer has been suddenly compelled to buy surplus power, and the central station has been the only source of adequate relief.

The central station has long laid its plans to meet just such a situation. Wonderful strides have been made in the development of large and efficient generating units and of economical means of transmission and distribution. Turbine-driven generators have been developed, having many times the capacity necessary for the operation of the largest single manufacturing plant. Boilers for producing high-pressure steam and superheating it have increased enormously in size and efficiency, and economical stokers and auxiliary boiler house equipment have kept pace with the increasing size of the boilers.

This parallel advancement in engine room and boiler house has made possible efficiencies not dreamed of formerly and not available in the smaller plants still in operation. Labor costs per unit of energy produced have gone down in unison with the lowering costs brought about by the increasing size of the units installed. Few manufacturers would view this rapid development with other than alarm, as few would care to hazard an investment which would so quickly become obsolete. Without this progressive investment, however, the highest efficiency in power generation is not possible.

The central station, by courageously installing the largest and most modern units, has obtained a high standard of efficiency in power generation. No manufacturer can afford to adopt this expensive policy. As a matter of fact, the manufacturer cannot successfully compete with the central station, because the investments of each are not in proportion. Spare units are necessary to insure reliability of service, but the percentage of these in the large central station is much smaller than in isolated plants, for the reason that the central station measures its spare capacity by the diversity of the needs of its customers.

The manufacturer has no such relief. He must make provision for his own maximum power demands and his idle capacity is, therefore, in greater proportion than that of the central station. The maximum demands of different manufacturing plants vary as to time, with the result that the central station can easily serve all with much less capacity than would be required if each manufacturer obtained his power from his own station.

It follows, then, that in any industrial community the consolidation of power-producing machinery in one plant not only decreases the amount of apparatus required, but keeps that which is installed in productive use a larger percentage of the time. This not only diminishes the amount of capital needed in that community for the production of power, but actually increases the use that is made of the lesser investment. Consolidation makes possible the installation of the largest and most efficient generating units and results in a corresponding reduction in operating costs.

Rapid advances in the art of transmission make it practical to send large quantities of electrical energy at high voltage long distances with very small line losses. In this way large quantities of power can be delivered at a lower cost than is possible where small quantities

sent to many different points add enormously to the expense of distribution and multiply the losses in transit. This ability to wholesale energy at distant points widens the area available for manufacturing purposes and reduces the investment of the manufacturer. Since industries are no longer forced to generate their own power, they are able to move away from congested and costly locations near large streams to more suitable, larger, cheaper and cleaner sites where better living conditions will improve the standard of the operatives employed.

The investment saved to manufacturers by eliminating separate power plants is often vital. Such plants involve an outlay of from 10 to 50 percent of the entire capital required and, as many new manufacturing enterprises are hazardous, the saving of this proportion of the proposed investment often means the difference between failure and success.

An efficient central station means more for the industrial development of the community than any other single agency. It offers the manufacturer cheaper power than he can make for himself; it eliminates that proportion of his investment which he has set aside for power generation; it offers a reliable service, available at any time and possible of expansion at a moment's notice, and it presents a prompt and permanent solution of the smoke problem existing in every industrial community. The elasticity of central station service enables the speedy enlargement of manufacturing capacity without the delay and expense incident to isolated plant extension. It is bound to encourage the location of small industries in widely varying localities suitable to their particular needs, by placing at their disposal large or small amounts of power at very low cost. This is certain to give a wonderful impetus to industrial development when the manufacturer learns to appreciate the opportunity open to him.

There is no other agency in any community that can be made to contribute in a greater degree to the prosperity and rapid development of that community than the central station. The interests of the community and the central station are closely interwoven and interdependent. The central station cannot prosper unless its community prospers. The community cannot attain its maximum development and the greatest degree of prosperity unless its central station is sufficiently prosperous to attract capital in adequate amount to enable it to anticipate the future needs of the community and to venture the investment that will permit it to meet fully its duty and responsibility to that communiy.

Some Practical Considerations in Artificial Ventilation of Electrical Machinery*

B. G. LAMME
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Westinghouse Electric & Mfg. Company

IN THE artificial cooling of power house and substation apparatus, especially that of large capacity, a number of conditions have developed from time to time which have given trouble or which have provoked more or less discussion. A number of these points are here presented briefly.

QUANTITY OF AIR REQUIRED

There is a very definite physical relation between the heat which must be dissipated from a machine, the resultant temperature rise, and the quantity of air which is passed through the machine to carry away the heat. The law is that one kilowatt of loss dissipated into the air will raise 100 cu. ft. of air 18 degrees C. in one minute. Therefore, if there is a definite loss to be dissipated by the ventilating air and a desired limit to the permissible rise in the temperature of the air leaving the machine, then there must be a definite volume of air per minute through the machine. The problem then resolves itself into getting this air through the machine or apparatus. An allied problem lies in the means for getting the heat from the copper or iron to the air, but this is part of the designer's work and does not enter here.

PRESSURE REQUIRED TO OBTAIN DESIRED QUANTITY OF AIR

The pressure required for a given quantity of air is dependent upon the size of air passages or apertures, upon the shapes of the ducts, i. e., number of bends, abruptness of bends, length of ducts, etc., and upon the velocity of the air. Too small passages means high velocity of the air, with consequent high pressure required. However, with many classes of artificially-cooled apparatus, the space available for air passages is comparatively small at some places, so that the air velocities are very high. This means ventilation losses, but in many cases these are unavoidable without radical changes in design which, in themselves, would mean increased losses of other sorts equal to, or greater than, the possible reduction in ventilation loss.

Usually, the greater part of the pressure developed by the ventilating fans is used up in the ducts or passages through the machine itself. However, not infrequently, part of the pressure is taken up by restrictions of some sort in the inlet or outlet conduits. If the machine is self-cooling in the sense that the rotor carries

*Revised by the author from a discussion before The Association of Edison Illuminating Companies, September, 1915.

its own fans, then such restrictions in the conduits may very seriously affect the quantity of air which passes through the machine. It is, of course, possible to make the ventilating fans of greater capacity, just to take care of such contingencies, but this would be penalizing good engineering to take care of bad, for the losses due to windage would then be unduly large where proper conduits are furnished. Cases have been noted where as much as 30 to 40 percent of the available pressure has been taken up by improperly designed inlet pipes.

Where the ventilating fans are driven independently of the main rotor, that is, by motors, it is practicable to vary the air pressure to suit the requirements, provided the driving motor can have its speed adjusted over a suitable range. This makes the ventilation more or less independent of restrictions. It has the further advantage of allowing the quantity of air to be varied to suit the load conditions. By this means an increased quantity of air, but with correspondingly increased windage loss, is available with heavy loads, while less air with lower losses may be used at lighter load. This arrangement is somewhat more efficient than the self-cooled arrangement with the fans on the main motor shaft, principally because of the excessively high fan speeds common in the latter case, especially on turbogenerators in which fan speeds far above efficient operation are used. In fact, in high-speed turbogenerators fan efficiencies of 20 to 30 percent are not unusual. Much better efficiencies can be obtained from separate slower speed fans (50 to 60 percent). However, the reduction in windage losses is not proportional to the increased efficiency of the fans, for part of the windage loss is due to "churning" of the air passing over the rotor, and this will be present regardless of the method of supplying air to the machine and is, to a certain extent, a function of the quantity of air which passes through the air-gap. This part of the windage loss is, therefore, greater in those machines where all the cooling air passes through the air-gap than is the case with those types where a considerable part of the air passes directly through the armature core, as in axially ventilated stators. In either type of ventilation, variation in the quantity of air with load is advantageous.

DISPOSAL OF HOT AIR

This was a matter of little importance in the days of small capacity per unit-area of generating room. However, in these latter days, where capacities of from three to ten times those of former days are developed in the same space, the question of disposal of hot air from the machines is becoming important. Large turbogenerators may require from 50 000 to 100 000 cu. ft. of air per minute. Five or six such machines in one generator room, operating at full load, means 250 000 to 500 000 cu. ft. of air per minute pouring into the room, this air being from 20 to 25 degrees C. above the normal air temperature. Obviously some provision should be made for getting this hot air out of the room. In the average generator room, the total cubical capacity of the room will be only five to ten times the total volume of air passing through the machines per minute. This gives a good quantitative idea of the extent of ventilation required in order to prevent undue temperature rises of the room air. In some of the more modern stations provision has been made for exhausting the hot air from the machines into the boiler room.

DIRT IN THE AIR

The enormous quantity of air required for ventilating large turbogenerators brings up the question of amount of dirt carried into the machines by such air. Assume, for instance, 60 000 cu. ft. of air per minute through a given machine. This weighs approximately 4800 pounds. The usual turbogenerator will, therefore, pass through itself, each thirty to forty minutes, a weight of air equal to its own total weight. Or, presenting the matter in another way, 45 000 000 cu. ft. of air passes through in twelve hours. Assuming as a rough approximation, that only one hundred-millionth of the volume of air consists of dust or foreign particles, then the above means that 0.45 cu. ft. of dust passes through the machine in twelve hours, or 45 cu. ft. in 100 days of twelve hours each. If the air inlet is in a dusty place, the above is not at all an impossibility. Of course, a considerable part of this dust will go directly through the machine, but in the air swirls and eddies inside the machine some of it will be deposited, and eventually this becomes a considerable handicap to the ventilation. This dust acts harmfully in two ways. In the first place, it may partially close the ventilating passages and thus decrease the quantity of ventilating air. In the second place, it may form a coating upon the heat-radiating surfaces so that the cooling air cannot come directly in contact with such surfaces. Ordinarily, in dissipating heat from a surface to the air a thin film of hot air adheres to the surface, and the heat is conveyed from the surface through this film to the moving air. With high velocity air striking the surface this film of hot air is scoured away from the surface, so that new air continually comes in contact with the surface. If, however, a coating of dust, or of other heat-insulating particles, gathers on the surface, then the ventilating air cannot come in direct contact with the surface and the heat-dissipation is at a lower rate. Dirt is particularly liable to adhere to the surfaces in case minute particles of oil are carried into the machine.

AIR WASHERS

Air washers are now being installed very generally in large generating plants to clean the air which passes through the machines. These washers have beneficial results in two ways. In the first place, they clean the air, thus preventing, to a great extent, the deposit of dirt in the machine. In the second place, they cool the air in hot weather, thus directly improving the capacity of the machine by allowing a greater temperature increase without exceeding a specified limit of temperature. A number of attempts have been made to cool turbogenerators by means of water in suspension in the

ingoing air, that is, by "fog." Such methods as yet have shown no particular promise.

Instances have occurred where fine, dry snow has been drawn into artificially-cooled apparatus and there melted, with the formation of water on the windings. This can only happen in cold weather and could be avoided in several ways. An opening from the inside of the building could be provided in the air intake so that the ventilating air is not taken from the outside. Another method would be to use the air washer at such times, by which means the snow would be abstracted. It is usually not considered advantageous to operate the washers during extremely cold weather, but in case of incoming snow there may be considerable advantage in operating the washers.

ZERO AIR, AND WATER DEPOSIT

A number of instances have been noted where, with the incoming air at an extremely low temperature (near zero F.), the end windings of turbogenerators were found covered with a film of water. In one case this proved disastrous. Apparently this was not condensation of water from the air, in the ordinary sense, for the armature windings were much hotter than the incoming air. One explanation is that this is due to "frozen fog," or ice particles in suspension, which melt when they come in contact with the heated parts of the machine. One remedy for this trouble is in the use of doors from the interior of the building to the inlet pipe, which can be opened in extremely cold weather to admit warmer air.

FIRE HAZARDS IN ARTIFICIALLY-COOLED MACHINERY

When a fire is started in such apparatus the artificial ventilation tends to spread the fire very quickly, especially in turbogenerators. Various remedies have been proposed, such as firedoors or dampers in the inlet conduits, the use of "fireproof" end windings, chemical extinguishers, etc. Firedoors have proven only partially effective, possibly due to the fact that it is difficult to shut off the air completely. For instance, in a machine taking 50 000 cu. ft. of air per minute, if 99 percent of the air is shut off, the remaining 500 cu. ft. which can pass through the machine may be sufficient to maintain quite a destructive blaze. Furthermore, there are liable to be small leaks around the end housings of the machine which will admit a little air.

It has also been suggested that equally good results would be obtained by enclosing the outlets from the machine in case of fire, thus retaining the products of combustion inside the machine, these forming a fairly good fire extinguisher in themselves.

As regards chemical extinguishers, these are practically useless unless the incoming air can be almost completely shut off. With 50 000 cu. ft. of air, for instance, passing through a machine, the small amount of gas which the extinguisher could furnish would be so diluted as to be worthless. One point to keep in mind in applying extinguishing gases is that they must be applied at the incoming side of the fan.

In some cases of fire the operators have turned on water from high-pressure mains, on the theory that, while water may ruin the insulation, yet fire may result in still greater damage.

Various attempts have been made to produce "fireproof" insulations for the end windings of turbogenerators. The difficulty lies in the fact that available fireproof materials, such as mica and asbestos, cannot be used alone. Mica requires some supporting or binding material, while asbestos requires some filling varnish in order to obtain suitable insulating quality. It is these binding or filling materials that are the real source of trouble, for these give off gases if the temperature is sufficiently high, and these tend to maintain or increase the blaze. Thus the outlook is not very promising.

When the initial blaze is produced by a short-circuit or arc inside the machine, a sudden interruption of the excitation, by killing the voltage, may extinguish the arc before a general conflagration is established. If the excitation is from a motor generator across the terminals of the machine, then a short-circuit in the machine may automatically shut down the exciter set. In the same way, if the ventilating fan is driven by a motor across the terminals of the machine, the ventilation may decrease automatically.

The above covers various suggested methods for preventing damage by fire inside such apparatus. All of them are admittedly defective, but each of them possesses some merit. A simple satisfactory method of fire protection for such apparatus is much to be desired.

NOISE

Recent high-speed turbogenerator rotors are all of the cylindrical type, with relatively smooth exterior surfaces. Nevertheless, due to their enormously high peripheral speeds and the great quantity of air through the air gaps, there is always very considerable noise developed inside the machines themselves. As such machines are always very completely enclosed, except through their outlet and inlet pipes or openings, these latter are usually responsible for any complaints regarding noise. Several cases have developed where the inlet conduits, opening directly to the outside of the building, have permitted undue noise. In other cases, sheet metal conduits have acted as sounding tubes and apparently have exaggerated the noise. Changing to plaster-filled expanded metal conduits has helped in some cases. In other cases, carrying the conduits up to the roof of the building has proved effective. A secondary result of this arrangement is that cleaner air is obtained, unless the inlet is exposed to an undue amount of dirt from the chimneys.

Electric Service Problems and Possibilities*

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EVERY branch of human endeavor toward advancement has its problems and its possibilities. Some of these affect or interest comparatively few people; others affect the comfort and convenience of very large numbers of people. The latter is especially true of public utilities. The rendering of electric service to large numbers of people is the newest utility and, for that reason, as well as because of its rather complicated nature, it is not so well understood as most of the other utilities.

INCREASE IN DEMAND FOR SERVICE

According to the census of 1912, the capital invested in the United States in the business of supplying electric service was upwards of two billion dollars. Today it is about three billion dollars.

While the principles underlying electric service are similar, there are often local conditions that make the solution of some of the problems in one locality different from another equally good solution for another locality. In order, therefore, to illustrate with more definiteness and clearness the problems and possibilities in the rendering of electric service, references will be made here to developments in Chicago, with which the writer is most familiar.

The increase in maximum output each year from 1888 to 1916 is shown graphically in Fig. 1; also an estimate until 1930. The maximum output in one hour in November, 1915, averaged 337 000 kilowatts. According to estimates, the maximum hourly output in 1930 will exceed 1 000 000 kilowatts.

RELATIVE DENSITY OF DEMAND

One of the important factors that affect the cost of rendering electric service is the density, that is, the quantity of electricity used in a given area.

The maximum density of Chicago is in the loop district, where the average is 80 000 kw per square mile. The minimum density is in the western part of the southern zone and is only 68 kw per square mile.

GENERATING STATIONS

The Northwest Station is located reasonably central for the entire northern zone, although at the present time it is located some two miles west of the "center of gravity" of the present load in that zone. The future growth must inevitably be toward this generating station, which will make its ultimate location much more central than at present. The present installation in the Northwest Station consists of two 20 000 kw and one 30 000 kw steam turbine-driven generating units. An additional 30 000 kw unit is in process of installation, and two 35 000 kw units have recently been ordered for installation in 1917. When these are in service the capacity of this station will be 170 000 kilowatts.

The Fisk and Quarry Street Stations are likewise located reasonably central to the zone they are designed to supply, and also at this writing within one mile of the center of gravity of the electric load in the entire city. In 1902 this location was nearly three miles from the center of gravity. The selection of this location has, therefore, proven fortunate. The Fisk Street Station at present has ten steam turbine generating units of 12 000 kw each, one of 25 000 kw, and one of 20 000 kw, or an aggregate capacity of 165 000 kw. The steam consumption of the latest two units is about 11.5 lbs. per kw-hr. In addition, the latest double boilers are equipped with economizers and have many other improvements. The use of higher steam temperatures will make possible still better economies in future, but will also necessitate the solution of many additional problems to insure reliability of service and low maintenance costs.

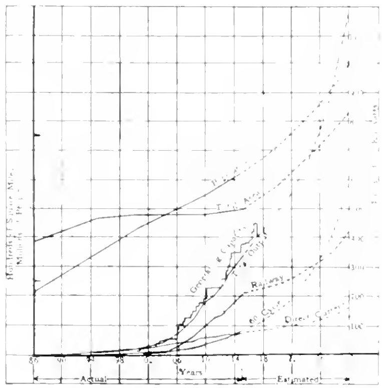

FIG. 1—ELECTRIC SERVICE IN CHICAGO

Past and possible future use 1888-1930. The estimates of increase in area and in population are approximately those used by Mr. B. J. Arnold in estimating transportation, and by the Chicago Telephone Company in estimating telephone requirements for 1930.

The Quarry Street Station has six 14 000 kw steam turbine generating units of similar design to the ten 12 000 kw units in the Fisk Street Station just across the river. In the building of such a generating and transmission system it is advisable to avoid concentration of too large a proportion of the total generating equipment in any one station or section of a station. It is also necessary to secure the greatest ultimate rather than immediate economy of investment. The equipment

*Condensed from a paper appearing in the February, 1916, issue of the *Transactions of the Engineers' Society of Western Pennsylvania.*

is today not yet complete, as there is room for two more large units.

Properly controlled imagination, that valuable asset so frequently undeveloped or lacking even among engineers, has rarely been found consistently adequate in the proper development of electric service for every purpose in a growing community. Such proper development also requires continuity of policy, loyally supported by a skilled and well-balanced organization. This is possible only by affording a reasonable tenure of authority and employment. It is practically impossible with such uncertain tenure as would result, for instance, from the success of this or that faction or political party.

ELECTRICAL ENERGY AND ELECTRIC SERVICE

There is a very wide difference between the mere supplying of electrical energy and the rendering of complete electric service, and hence also in the price. The supplying of electrical energy in bulk at a high voltage to railway companies or to large industrial establishments is comparatively a simple matter. It means the

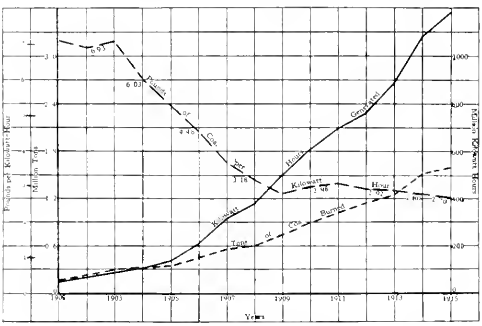

FIG. 2—CURVE SHOWING COAL CONSUMPTION AND INCREASED EFFICIENCY IN USE OF COAL

delivery of a raw product, or at best a partially finished product not yet in usable form. The only investment charges or maintenance expenses required are those for the generating station and high-tension transmission lines. The only operating expenses are those for the generating station, of which the cost of coal is about 75 percent. After adding the investment charges at, say, a 40 percent annual load factor and the small proportion of general expense usually incurred, the cost of coal is still in the order of 33 percent of the total cost of supplying high-tension electrical energy in bulk.

RELATIVE COAL COSTS

Contrast this with complete retail electric service to homes in which the cost of coal is usually less than four percent. The cost of the raw product (coal) has here become a very small proportion. The very large proportion of the cost to render electric service to homes is that due to very heavy investment charges and to very expensive service. At present the average consumption at all Chicago stations is about 2.7 lbs. per kw-hr. The coal consumption of the latest units averages about 1.95 lbs. per kw-hr. About one-half the yearly output is being generated by steam turbine-driven units of 20 000 kw and larger capacity.

CONSERVATION OF COAL

During the year 1915 the output was about 1 200 000 000 kw-hr. and 1 586 000 tons of coal were required. At the coal consumption per kw-hr. which prevailed in 1903, a total of 4 195 000 tons would have been required. The saving in coal in 1915 alone was, therefore, 2 609 000 tons. This conservation of coal is due to steam, electrical engineering and new business development. Low electric power costs are obviously of great benefit to almost every community. Unless water power is available, the cost of fuel is the factor of first importance. After that, the securing of sufficient business at some profit and the skillful physical development of a system are closely interlinked problems, the solution of which must be judiciously co-ordinated.

RELATIVE INVESTMENT REQUIRED AND EFFECT OF DENSITY

The high-tension transmission system in Chicago, over which 337 900 kw was transmitted in November,

TABLE I—RELATIVE INVESTMENT FOR THREE DIFFERENT CUSTOMERS

Items.	A	B	C
Generating Station	12.3	12.3	12.3
Transmission System	3.2	3.2	3.2
Substations	....	4.4	4.4
Distribution to block in which home is located	....	9.3	9.3
Distribution within such block	....	58.6	12.
Meters	....	9.	9
Lamps	....	3.2	3.2
Total	15.5	100%	53.4

Column A—Supply electrical energy untransformed at a substation.

Column B—Electric service to one of five residence customers in a block.

Column C—Electric service to one of fifty residence customers in a block.

1915, to 76 substations, consists of 725 miles of underground three-conductor cables and 12 miles of overhead three-conductor lines. The distribution system beyond these substations consists of 2050 miles of single conductor underground and 7850 miles of single conductor overhead wire. In an area of seven square miles in the downtown district all conductors are underground. In all the remainder of the city the distribution is partly underground and partly overhead. The feeders or circuits from the substations are carried underground in streets for distances of one to four miles and then overhead in alleys. The primary distribution is 2300-4000 volts, four-wire, three-phase. Such portions of these circuits as carry no power are single-phase, to which a third wire is added when power is added to the load.

In Table I, column A shows approximately the relative investment required to supply electrical energy untransformed at a large substation; column B that to render electric service to one of five residence customers in a block; and column C that to render service to one of 50 residence customers in a block. Assume (a) that

the electric utility has only two classes of customers and (b) that the yearly load factor of each customer in the two classes is the same, and (c) that the same yearly fixed charge could be applied to the entire investment used for each customer, then the investment charge for the consumer of untransformed energy would be only 15.5 percent of that for the residence customer who is one of five customers in a block. This refers to column B, where there are only five small residence customers in a block. If there are fifty similarly small customers in a block, as in the case of large flat buildings, the total investment charge as shown in column C is reduced almost one-half. The reason for this large reduction is, that for mechanical reasons the poles, the primary wires and the secondary wires necessary for five customers to the block are also sufficient to supply 50 customers to the block. The only additional investment for 50 customers instead of five is the larger transformer and the additional number of service drops. If every block in a city or in an area served had 50 or more customers there would be a considerable reduction also in the items of transmission, of substations and of distribution to the boundary of the block. The above illustrates the very great influence of density on investment required to render electric service to homes. It also shows that the investment per unit of demand is six or seven times as great for the small customer in column B as for the large customer in column A. The interest and other fixed charges in this investment must be paid from month to month and year to year. These interests and other fixed charges go on and on and must be paid when the customer uses the service only five minutes per day as well as when he uses it five hours per day. This is one of the reasons why a minimum bill each month is equitable and fair.

RELATIVE EXPENSES OTHER THAN INVESTMENT

All of the expenses per kw-hr. (other than fixed charges on investment) incurred in supplying electrical energy untransformed in bulk are only about six or seven percent of those incurred in rendering electric service to a very small customer. In the case of untransformed energy in bulk the only large expenses are those of operating and maintaining the generating station and the transmission lines. The cost of reading and maintaining meters and rendering and collecting of bills for such large customers is relatively a very small item.

TABLE II—ELECTRIFICATION IN CHICAGO.

Energy Requirements at Pantograph—2400 Volt Direct-Current System

Railroad.	Average Day		Average Hour	Maximum Hour		Load Factor
	Kilowatt-Hours	Per Cent. of Total	Kilowatt-Hours	Kilowatt-Hours	Per Cent of Total	
Atchison, Topeka & Santa Fe Railway	20 537	1.38	856	1 325	1.21	64.6
Baltimore & Ohio Railroad	29,333	1.97	1 222	1 604	1.47	76.2
Baltimore & Ohio Chicago Terminal Railroad	35,355	2.38	1 473	2 067	1.89	71.3
Calumet, Hammond & Southeastern Railroad	2 217	0.15	92	148	0.14	62.2
Chesapeake & Ohio Railway of Indiana	3 016	0.20	126	349	0.32	36.1
Chicago & Alton Railroad	24,388	1.64	1 016	1 589	1.45	63.9
Chicago & Calumet River Railroad	2 407	0.16	100	137	0.13	73.0
Chicago & Eastern Illinois Railroad	26 400	1.77	1 100	1 890	1.73	58.2
Chicago & Erie Railroad	3 640	0.24	156	885	0.81	17.6
Chicago & North Western Railway	288 228	19.37	12 010	23 438	21.40	51.7
Chicago & Western Indiana Railroad and the Belt Railway of Chicago*	113 567	7.63	4 732	6 915	6.33	68.4
Chicago, Burlington & Quincy Railroad	67 655	4.54	2 819	6 464	5.92	43.6
Chicago Great Western Railroad	9 704	0.65	404	885	0.81	45.6
Chicago, Indiana & Southern Railroad	3 126	0.21	130	663	0.61	19.6
Chicago, Indianapolis & Louisville Railway	11 812	0.79	492	1 054	0.96	46.7
Chicago Junction Railway†	49 638	3.33	2 064	2 746	2.51	75.2
Chicago, Milwaukee & St. Paul Railway	130 512	8.78	5 438	8 117	7.43	67.0
Chicago, Rock Island & Pacific Railway	70 046	4.71	2 919	6 035	5.52	50.2
Chicago Short Line Railway	1 950	0.13	81	126	0.12	64.2
Chicago, West Pullman & Southern Railroad	8 260	0.55	345	426	0.39	81.0
Elgin, Joliet & Eastern Railway	40 318	2.71	1 680	2 526	2.31	66.5
Grand Trunk Western Railway	19 348	1.30	806	1 410	1.29	57.2
Illinois Central Railroad	140 521	9.45	5 855	12 021	11.01	48.7
Illinois Northern Railway	4 043	0.27	168	288	0.26	58.3
Indiana Harbor Belt Railroad	6 999	0.47	292	894	0.82	32.7
Lake Shore & Michigan Southern Railway	100 747	6.77	4 198	7 225	6.61	58.1
Michigan Central Railroad	42 092	2.83	1 754	2 386	2.18	73.5
Minneapolis, St. Paul & Sault Ste. Marie Railway	5 729	0.38	239	605	0.55	39.5
New York, Chicago & St. Louis Railroad	21 617	1.45	901	1 344	1.23	67.0
Pere Marquette Railroad	13 311	0.89	555	1 086	0.99	51.1
Pittsburgh, Cincinnati, Chicago & St. Louis Railway	56 444	3.79	2 352	3 354	3.07	70.1
Pittsburgh, Fort Wayne & Chicago Railway	95 051	6.39	3 960	6 467	5.92	61.2
Pullman Railroad	2 838	0.19	118	254	0.23	46.5
Wabash Railroad	37 711	2.53	1 571	2 535	2.32	62.0
Totals	1 488 550	100.00	62 023	109 258	100.00	

*Includes Chicago Union Transfer Railway. †Includes Chicago River & Indiana Railroad.

In the case of the very small customer, the operating and maintenance expenses in connection with the substation, complete distribution system, meters and lamps, and often certain free repairs for customers, are a very large item. The general expenses incurred in reading, testing and maintaining meters, rendering and collecting bills and keeping and carrying the account is just as great for the smallest customer as for a large customer. Here then is another reason why a minimum bill is necessary.

The rendering of such general repair and inspection service day and night for convenience of customers, as is demanded in rapidly increasing proportions, amounts to

a very large sum at the end of the year. There are also heavy seasonal expenses. For example, about 30 percent of all residence customers in Chicago, or 82 000 customers, moved from one location to another in 1915. Most of them want to be disconnected and reconnected at a specified day and hour. This means an enormous strain on employes, as it is impossible to render such service with new people employed for a few days during the May 1 and October 1 rush. Other work must, therefore, be neglected to some extent and all efforts concentrated on this enormously expensive semi-annual moving.

METERING AND BILLING METHODS

The cost of reading the meter each month, entering on the books, rendering the bill and making the collection, is about 16 cents per bill. This is repeated 12 times a year. This is a large proportion of a bill for electric service that is often $1.00 or less per month.

While the present type of electric meter is a wonderfully reliable and accurate instrument for the price, there is after 30 years of development still room for revolutionary improvements. The possibilities of simplified methods in metering, billing and collecting, and hence of relations with customers, are very great, and the necessity for such simplification is becoming more urgent year by year.

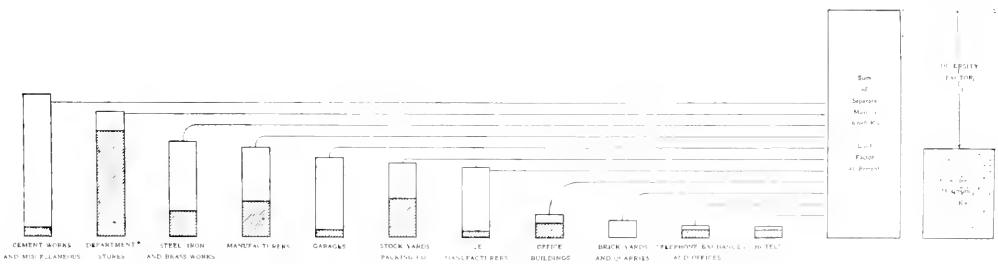

FIG. 3—DIVERSITY OF LARGE LIGHT AND POWER CUSTOMERS

INCREASING THE OUTPUT

Two extreme cases have been considered, one a very large and one a very small customer. The investment cost per kilowatt demand was nearly seven times as great for such residence customer, and all other costs per kw-hr. of use about fifteen times as great for such residence customer as for the street railway. A large proportion of the business of an electric utility, however, lies between these two extremes. It is a very difficult matter to determine accurately the relative cost to supply each of the many different customers under widely varying conditions of service between the two limits considered above. It is, however, necessary to keep the matter of cost constantly in mind, because any customers that are served below cost involve a loss that must eventually be borne by other customers. It is one of the present problems of every electric utility to so conduct its business that the number of customers served below cost shall not become too large and thus prevent an injustice to other customers.

Even if it were possible, it is, however, not at all necessary that all customers should afford the same percentage of profit. In a great many instances it is necessary in order to secure additional customers that they be served at a lower margin of profit than is afforded by some existing customers. Every customer added to the utility, if he affords any profit at all, is a source of benefit to all of the other customers, provided always that there is no discrimination in rates under like conditions of service. Take for example again, the electric railway load in Chicago. During the first two or three years this railway business was served at practically no profit. The demonstration was, however, successful, and as a result the sale of electrical energy to the railways increased rapidly and soon afforded a reasonable profit. Since then this railway business has made possible the very large and economical power houses and transmission systems from which all of the other customers have since received very large benefits, as demonstrated by the various reductions in rates. In this respect the sale of electrical energy is not essentially different from the sale of the output of a manufacturer who makes a moderate profit on his regular line. In order, however, to run his factory more economically it is advisable for him to take on an additional line and, if possible, a line that can be manufactured during the particular season of the year when the demand for his regular product is at a minimum. When first taking on the additional line he is entirely justified in doing so at a low margin of profit or no profit at all, and by so doing increase the quantity of his entire production so much that he is finally able to cut down the margin of profit both on the standard line and on the additional line, thus benefiting both his old and new customers.

The fixed charges on investment, interest, depreciation and the like are the largest portion of the cost to serve the majority of users of electric service. The matter of load factor is, therefore, of vital importance, that is, if a dollar invested in the electric utility can be made to work twice as many hours per day the fixed charges are correspondingly reduced. This is what happens if the same equipment can be used to supply one or a set of customers during the early hours of the day and another set of customers during the evening and night hours with no overlapping of the two demands. In most cases this is only partially true. This so-called diversity of

demand is a fundamental and important economic reason for massing of production on a large scale.

An exhaustive study was made two years ago of the demand of 82 customers, which were classed into 11 groups as follows and shown in Fig. 3:—Department stores, office buildings, hotels, telephone exchanges and offices, garages, brickyards and quarries, steel and brass works, ice manufacturers, general manufacturers, stockyards and cement works. The consumption of electricity for each of these 82 customers was automatically printed at the end of each hour by printometers. The hour, as well as the amount of the maximum demand of each one of the 82 customers, was thus made available. The sum of the separate maxima was 26 640 kilowatts. The coincident maximum, however, at the time of maximum demand (about 5 P. M. in December) was 9770 kilowatts. This means a diversity factor of 2.7. Some of the 11 groups, such as brickyards, cement works and ice manufacturers, made practically no demand at that hour and season. Certain others, such as steel, iron and brass works, general manufacturers and the like, make their greatest demands about 10 A. M.*

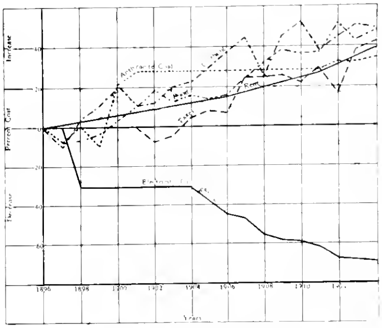

FIG. 4—INCREASED COST OF LIVING CONTRASTED WITH DECREASED COST OF ELECTRICITY FOR LIGHTING

REDUCTION IN COST OF ELECTRICITY FOR LIGHTING

The annual output from 1896 to 1915, inclusive, increased from 15 700 000 kw-hr. to 1 198 637 000 kw-hr., i. e., the output in 1915 was 75 times greater than in 1896. This made possible material reductions in the average price of electricity for lighting, as shown in Fig. 4. Prior to 1898 the rates were 20 cents per kw-hr. At that time the Wright demand system was put into effect for the first time in America. This made it possible for long-hour profitable users to earn a better rate automatically. This resulted in the rapid increase in the sale of electrical energy for all purposes. The curve shows that since 1904, when the advantages of central station power supply began to be better appreciated by the community, the average rates for lighting decreased steadily. While the cost of electricity for lighting has decreased 70 percent, the cost of living, such as food, clothing, rent, taxes and coal, based on United States Government and other authoritative reports, increased more than 40 percent. During this period other users of electricity also received some benefits in rates. The income from electric railways for energy increased from $27 030 in 1902 to over $5 000 000 in 1915, as shown in Fig. 5. During the last nine years of this period the average rate to railways at 40 percent load factor, for untransformed energy at their substations, decreased 26 percent, largely because of the greatly increased quantity. Practically all customers between these two extremes have also enjoyed corresponding reductions in rates.

POSSIBILITIES FOR ADDITIONAL SERVICE

Notwithstanding the very large amount of energy distributed by the electric utility in Chicago (about 480 kw-hr. per capita per annum in 1915) the possibilities for the future are still very great, as illustrated in Fig. 6. The upper portion shows the amount of energy distributed for different purposes in 1915 to be as follows:—Homes, 53 284 000 kw-hr.; commercial electric service, 326 728 000 kw-hr.; electric auto charging, 14 300 000 kw-hr.; street and elevated railway, 680 112 000 kw-hr.

The lower portion of Fig. 6 shows the present percentage of ultimately possible service that might be rendered as follows:—Homes, 35 percent; commercial electric service, 30 percent; electric auto charging, 10 percent; street and elevated railway, 100 percent.

One of the principal reasons for the fact that only 30 percent of the commercial electric service is supplied by the electric utility is that the remaining 70 percent contains a considerable number of unusually large industrial establishments, such as the Illinois Steel Mills, Union Stockyards, Pullman Car Works and others; also that in this 70 percent is included a great number of establishments which still have mechanical drive. Even

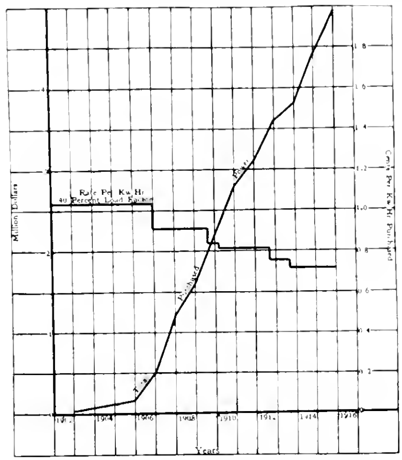

FIG. 5—INCREASE IN POWER PURCHASED BY ELECTRIC RAILWAY COMPANIES OF CHICAGO DURING FIRST FOURTEEN YEARS

*This study of diversity is referred to at length in a paper by Mr. Samuel Insull entitled "Centralization of Energy Supply," and delivered before the Finance Forum of the New York Y.M.C.A. on April 20, 1914

if only one-half, or say 350 000 000 kw-hr, per annum, were supplied by the electric utility, the advantage to the community would be considerable. Among them would be earlier and greater possible reduction in general retail rates, less smoke and dirt, less hauling of coal and ashes, conservation of coal and other advantages.

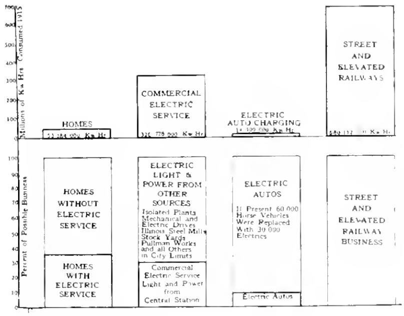

FIG. 6—PRESENT QUANTITIES AND LOAD POSSIBILITIES IN CHICAGO

It is for the best interest, therefore, of every retail user, present and prospective, that additional wholesale customers be secured by the utility.

POWER FOR ELECTRIFICATION OF STEAM RAILWAY TERMINALS

An additional possibility for a large amount of electrical energy that could be furnished very economically by some electric utilities is that required for the electrification of steam railroads. A committee of the Chicago Association of Commerce in 1915 made a very exhaustive report on the subject of smoke abatement, and incident thereto the electrification of railway terminals was considered. The report contained complete calculations on electrification on the basis of a 2400 volt direct-current system and also on the basis of an 11 000 volt alternating-current single-phase system. In Table II is shown the estimated power requirements for the 2400 volt system.

If the energy required were purchased from the electric utility it could, even at this time, be supplied from four different and large modern interconnected power houses already in existence. This would result not only in a saving in cost of transmission system, but also largely increased reliability of service. The amount of electrical energy required by the different railroads during the maximum hour varies from 126 kw for one of the industrial railroads to 23 438 kw for the Chicago & Northwestern Railway. The maximum demand corresponding to this maximum hour, after allowing for transmission and conversion losses, is 29 200 kilowatts at the power house. This, the largest requirement of any one of the railroads, is less than the rated capacity of any one of four units in service or under construction in the existing power houses of the electric utility. It is not probable that the maximum demand of each railroad would fall on the same day and hour as the maximum load of the electric utility. The maximum demand of all electrical energy on the electric utility, except a portion of that used in manufacturing establishments, is fixed largely by the habits and prosperity of the people in the city. The maximum demand of the energy used by a large railroad terminal would probably be fixed by the freight traffic on such system, and which, in the Mississippi Valley and beyond, is likely to occur in October or November.

If the railway terminals of Chicago are electrified, singly or in groups, those with the denser traffic will naturally be electrified first. Such railroad, or groups of railroads, could purchase just the amount of energy required to move their traffic. This would be a distinct advantage over building a power house for future requirements, and which would naturally involve, with proper reserve, a very considerable amount of unproductive investment during the early years of electric operation of such terminals. In other words, such electrified terminals if supplied from a new power house for this exclusive purpose would have to be operated under a handicap from the very beginning. In addition to this, the railroads by purchasing their power would be relieved from the burden of financing the power supply portion of the project. Most important of all, however, is the fact that in the end the public of the terminal city and the public using the railroad are benefited by the purchase of the energy needed for electrification. Moreover, if the electrification of the railway terminals required a period of from ten to twelve years, from the time that the first electric trains were operated until the final completion of the electrification, then the amount of additional generating equipment required each year by the electric utility in Chicago would be so small relatively as to almost come within the limits within which it is possible to estimate the growth of the business of the electric utility.

TABLE III—INCREASED USE OF ELECTRICITY IN APARTMENTS AND HOUSES

Month of October, 1908-1915, inclusive.

	Number of Customers	Average Kilowatt Hours per Customer
	APARTMENTS.	
1908	25 900	15.6
1909	37 940	16.6
1910	51 760	18.5
1911	67 806	18.0
1912	86 462	21.0
1913	110 649	24.2
1914	126 000	22.5
1915	141 620	22.9
	HOUSES.	
1908	5 232	30.0
1909	6 755	31.8
1910	9 135	33.4
1911	11 671	34.6
1912	12 912	37.6
1913	16 549	43.0
1914	19 492	29.8
1915	34 756	29.2

RELATION OF PUBLIC TO ELECTRIC LIGHTING

But to return again to the residence service portion of the business. After all, that is the portion that is

most conspicuous to the general public. The average residence customer is unconscious of the fact that he is using more and more electricity, as is indicated in Table III. This table is the result of a very careful analysis of the bills of all residence customers for each October from 1908 to 1915, inclusive. The month of October was selected, as this is an average, and is believed to represent nearer than any other month about one-twelfth of the annual use by residence customers. In October, 1908, 25 900 customers living in apartments used an average of 15.6 kw-hrs. per customer. In October, 1915, 141 620 customers used an average of 22.9 kw-hrs. each. This means during eight years an increase of approximately 50 percent in the average kw-hrs. used in October by customers living in apartments. Strangely enough, the average used by customers living in houses has not increased materially during this period. The increase in the number of houses was partly brought about by annexation and additional territory served, and the results of increased use of electricity in houses are, therefore, not as dependable as the results from the apartments.

A part of this increased use of electricity in homes is undoubtedly due to the increasing use of household appliances.

IMPROVEMENT IN LAMPS

The question of lamp policy is a most important problem. The quality of the lamp affects to a very marked extent the quality of lighting received by the customer. It is the one tangible portion of electric service that comes most strongly to the customer's attention. The customer feels that he is able to judge that element of the service, and yet it is a matter on which even experts, without the use of any instruments, might differ from 50 percent to 100 percent, unless, of course, they had a very high efficiency and a very low efficiency lamp of same wattage side by side. Without instruments it is almost impossible to compare the amount of

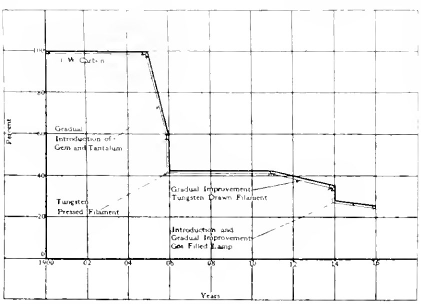

FIG. 7—CONSUMPTION PER CANDLE-POWER OF LAMPS OF MEDIUM SIZE IN PERCENT OF SIXTEEN CANDLE-POWER CARBON LAMPS

light received one year in a home for a given expenditure of money with that received during the same month one or two years earlier for the same expenditure of money from less efficient lamps.

The amount of light which \$1.00 would buy over a long period of years is shown in Fig. 8. Prior to 1898 \$1.00 would buy about 1200 candle-hours. This has increased during the past 17 years so that in 1915 \$1.00 would buy about 15 000 candle-hours. During this period the rate for electricity decreased 67.5 percent and the lamp efficiency increased 346 percent. The above is based on average retail lighting rates and on 3.1 watt

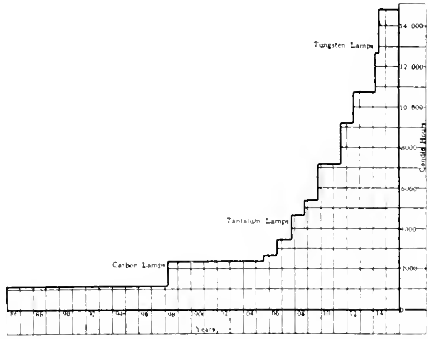

FIG. 8—AMOUNT OF ELECTRIC LIGHT THAT \$1.00 WOULD BUY YEARS 1886-1915

Expressed in candle-hours. Lamp efficiency increase, 346 percent; rate decrease, 67.5 percent.

carbon lamps in 1898 and 1.03 watt vacuum tungsten lamps in 1915. These facts are determined in an absolutely accurate scientific manner, and yet how few customers would appreciate that in 1915 they were getting 15 times as much light for \$1.00 as they were 17 years ago. This is another of the many problems whose only solution seems to be a constant campaign of education and publicity.

USE OF TELEPHONE IN RENDERING SERVICE

There are, however, some elements of electric service that customers can judge with reasonable accuracy, that is, the promptness or lack of promptness with which their requests for service are complied with. Such requests, many of which are made at moving time, often emanate from persons who are already nervous or worried about their own particular and immediate affairs. In many cases they have forgotten to make application for electric service until the very last minute. They are, of course, entitled to the most courteous and prompt attention and to due allowance for their possible state of mind. It is, therefore, not only a duty, but it is also good business for the electric utility to make every effort to give the customer the best possible attention. In a large city the number of people who come to headquarters or branch offices of the electric utility to make arrangements in person for service is becoming smaller and smaller. Those who use the telephone for this purpose are constantly increasing in number. Some electric utilities have, therefore, given much attention to the matter of telephone communication with their customers. In one instance, an electric utility in a large city has concentrated the telephone contact with its customers in three principal bureaus, known as the Application Bureau, the Service Bureau and the Customers' Account

Bureau. When the customer first calls for the electric utility he is connected by the telephone company with the electric utility's main exchange board. This board contains 20 positions and during 1915 handled 7 000 000 messages. When connected with this board, if the customer does not call for a particular bureau or make his wants definitely known, the telephone operator ascertains quickly and tactfully whether the customer wants to make an application for new service or whether he wishes lamps or other service, or whether he wants information regarding his account. The customer is then connected quickly with the proper one of these three principal bureaus.

During the busiest hour of April 29, 1915, there were 1425 incoming calls, of which 562, or ten per minute, were trunked to the Application Bureau. All of these calls were requests for service in new buildings or for reconnection in old buildings. There were 425 calls, or seven per minute, trunked to the Service Bureau in the same hour. These were for lamp renewals, replacement of fuses, minor repairs, and the like. There were also 50 incoming calls for the Customers' Account Bureau. These requests were mostly for final bills for people who had moved to a new location, and in some cases for duplicate bills.

The Application Bureau consists of a 20 position table. There is also an auxiliary 12 position table, which makes a total capacity of 32 operators to receive simultaneously 32 calls from customers desiring service. These order tables have signal lights that indicate in the vertical cabinet at the end of the table when a call is placed on the bureau, together with a buzzer signal, and any of the 20 operators on the table not busy can answer any call. A single operator on this order table has been able during the busy period to handle over 225 applications a day. This has a tendency to greatly expedite the rendering of service, as the experienced operator, in a tactful way, can secure exactly the information needed, which is not possible in many instances where requests are made by mail.

There is a 20 position order table in the Service Bureau. Four operators are called work dispatchers, who are in touch with the individual repairmen in various districts of the city, and when calls for fuses or repairs on wiring or household appliances are received they are recorded and dispatched by the carrier system directly over the table from the operators on the service bureau board to the work dispatchers, who sort them according to such districts, and transmit them hourly to the repairmen in the district. The lamp renewal requests are also sorted and then assigned to delivery routes for the next day. On December 20, 1915, 2880 calls of various kinds were handled by this Service Bureau. The number of calls handled per day averages about 1950. The order tables in these three bureaus are not completely manned at all hours, operators being recruited from the clerical divisions of the departments in charge of the bureaus, and being kept available during the rush periods of the day on these boards.

PUBLIC RELATIONS

The greater portion of the refinements in service are occasioned by the residence customers. They are in the majority; and in the last analysis they are ultimately in control. These residence customers in one large city, however, do not provide enough gross income to even meet the electric utility payroll.

The residence, rather than the commercial customers, are hardest to please. They want the lowest possible rates and the best possible service. They are unquestionably entitled to both if not carried to a point where it is against their best ultimate interest. If, for instance, residence rates were forced so low and quality of service so high that substantially all residence customers were served at a loss, the commercial and industrial customers might temporarily bear the extra burden. A part of the cost of the electric service for residences would then appear in increased price of provisions, clothing, amusements, and so on. Furthermore, this extra burden would mean that some industrial and commercial customers might then install independent plants and the electric utility would certainly not be able to get so many new wholesale customers. This would mean less income, less profits and certainly less chance for reduction in retail rates, if not an increase in retail rates. In a considerable number of instances, state public utilities commissions have found it necessary under such circumstances to raise retail rates. In those cases the forcing of retail rates too low, and of service too high, has been directly against the best interest of the residence customers and of the community, whose credit standing and integrity has been impaired.

In many cases states commissions have encouraged and even directed the electric utility to lower its wholesale rates with a view of increasing the volume of its business, and by this means finally to get into a position where it would be possible to reduce retail rates. It is, therefore, for the best interest of every user of electric service that additional customers be secured by the electric utility. This is true, first, from the standpoint of increasing the density of customers and thus converting unprofitable blocks into more profitable blocks, and second, from the standpoint of additional income from any customer served at a profit.

The supplying of all electrical energy needed for every purpose in any community or area from a single electric utility has been demonstrated again and again as being the correct economic solution. The greatest single problem remaining is the promulgation of mutual confidence and understanding. Engineers and business men are capable of carefully analyzing conditions, problems and possibilities. They can do much for their respective communities. Is it then not their duty to analyze, to understand and to take a firm position in favor of what is right and sound from a broad economic standpoint?

Recent Advances in Large Steam Turbine Practice

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THE PROGRESS made during the past four years in the development of steam turbine units of 15 000 kilowatts capacity and larger has been most extraordinary. Due to the rapidly increasing demand for electric power at cheaper rates and the development and use of high-voltage, high-efficiency transmission lines, both overhead and underground, there has been much activity in concentrating generating apparatus into fewer stations of larger capacity. This has resulted in continual demands upon turbine builders for generating units of larger capacity, greater reliability and greater efficiency. In this article the writer will confine his discussion to units manufactured by the company with which he is identified.

THE advances in the capacity of steam turbine generating sets during recent years are shown graphically in Fig. 1. In order to show the relation which the recent advance bears to that preceding, this diagram has been extended to include the first commercial steam turbines built in this country. Two curves are shown, *A* representing the maximum continuous capacity of the units and *B* the approximate maximum overload capacity. Up to about 1909 there was an almost constant rate of increase in sizes of units, but since that time the rate of increase has been increasing, until at present the curves are almost vertical.

The nature of the curves, however, do not differ materially from a curve showing the growth of the total amount of electric energy generated in the United States during the same period of years. This relation is readily explained by the fact that the steam turbine has been a very important factor in the development of the electric power industry. This industry has grown so that today stations of approximately 100 000 kw capacity are giving continuous and uninterrupted service to all of their circuits, some extending their transmission lines as far as approximately one hundred miles from the source of generation, and compelling the small isolated manufacturing and lighting companies to shut down their existing power stations and buy central station power purely because of the lower cost and better service. This result could not be secured with either steam or gas reciprocating units.

Recent practice has been to adhere to single cylinder construction for units up to between 25 000 and 30 000 kw capacity, while for larger sizes the multiple cylinder arrangement has been employed. The advantages of this system are quite real and significant. Turbines up to 20 000 to 30 000 kw, operating at 1800 or 1500 r.p.m., can be built in single cylinders without serious sacrifice of either thermodynamic or mechanical factors of design. If larger sizes are attempted the design must be compromised. It must be remembered that steam turbines, like other apparatus, must be built from materials commercially available, bearing in mind the fact that the same materials must be used for the very large structures as are available for the small ones. Any attempt to depart from these materials must be regarded as daring, if not dangerous. Of course, it may be argued that steels of 125 000 to 150 000 lbs. ultimate tensile strength and 75 000 to 90 000 lbs. actual elastic limit can be obtained. Therefore, why should they not be used? They should not be used for turbine rotors, for the reason that as yet they are more or less laboratory materials which, while perhaps technically possible of being produced of as even quality as lower grade steels, practically are not being so produced. The higher the quality of material, the more sensitive, accurate and exacting are the processes by which it must be produced. For example, a very slight deviation from prescribed temperatures in heat treatment will destroy the high quality of the material entirely. Defects such as blowholes or cracks cannot be detected any more accurately than in lower grade materials; therefore, defects of the same magnitude will exist in the finished product, particularly so near the axis of rotation, where the masses must be large. The percentage of the total mass included in the defects will, therefore, be larger, resulting in a larger percentage of increase in stress in the material. Therefore, the percentage of reliability of quality must be lower with the higher grade material, because if produced commercially it must and

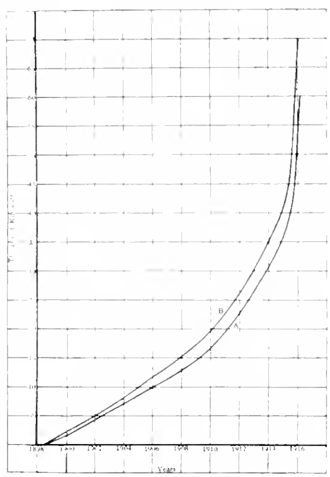

FIG. 1—INCREASES IN CAPACITIES OF STEAM TURBINE GENERATING SETS

will be produced with practically the same degree of skill and intelligence as is available for the less exacting product.

In a steam turbine where absolute reliability is essential the designer must not lose sight of the truth that steels will be made by steelmakers, castings by founders, machine work and assembly will be done by machinists, the inspection by inspectors, and that after installation the unit will be operated and maintained by present-day average operating engineers and mechanics. Years of special training in the building of one class of apparatus will, of course, enable an organization to produce a materially higher grade than would be possible with an untrained organization, but the relative effect of this training, as compared to the degree of development of the arts and artisans generally, is very slight.

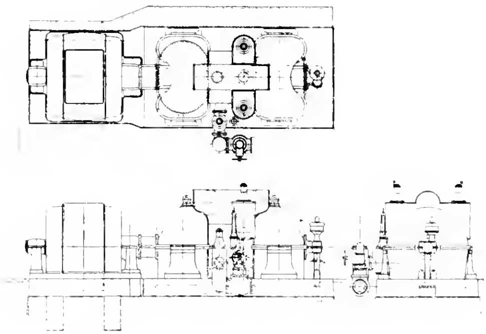

FIG. 2—3000 KILOWATT, SINGLE CYLINDER PURE REACTION UNIT 1000 r.p.m., 25 cycles.

Therefore, in units larger than 30 000 kw, in order to avoid exceeding safe and conservative factors of design, the turbines are built of two or more cylinders, through which the steam is made to pass serially, or part serially and part in multiple, depending on the volumes to be handled, the cylinders being arranged either in tandem, driving a single generator, or side by side, driving separate generators connected in parallel. A very important advantage gained by this construction is a reduction of the temperature difference existing in any one cylinder. With normal operating conditions of 200 pounds, 200 degrees F. superheat and 29 inches vacuum, the steam entering the turbine has a total temperature of approximately 588 degrees F., while its temperature when leaving is but 79 degrees F., a difference of 509 degrees. From two-thirds to three-fourths of this temperature change occurs in the small high-pressure cylinder, and from one-third to one-fourth in the large low-pressure cylinder. The effect of this in preventing distortion must be obvious. A further advantage is to be gained in many instances in weight and efficiency by operating the various elements at different rotative speeds.

15 000 TO 20 000 KW UNITS

In September, 1913, the Westinghouse Machine Company put in service its first 15 000 kw unit, and in the same year its first 20 000 kw. Both were single-cylinder turbines of similar design. They were what is known as double-flow machines of the combination impulse and reaction type, the steam dividing immediately after passing through the impulse element, and were designed for a higher vacuum than any machines previously built. Their success was most gratifying, as is evidenced by the fact that eight machines of the smaller size were sold within a period of two months.

30 000 KW UNITS

During the latter part of 1913 a contract was closed for three units of 30 000 kw continuous capacity each. This was an increase in size of 50 percent above the largest previous unit. The proposed design of these turbines was the subject of much thought and calculation, and a number of alternative designs were carefully analyzed. The two-cylinder, cross-compound, pure-reaction design was finally determined upon as possessing the greater merit. These units have been in operation since about the first of 1915.* The construction of these units was significant for the reason that they introduced the multiple cylinder, multispeed design of turbine unit, a design which at present seems to be the proper and logical solution of the large unit problem.

Recently a 30 000 kw single-cylinder turbine of pure reaction type and semi-double-flow design, operating at 1500 r.p.m. has been developed. This machine has some advantages over the two-cylinder construction in lightness, cost and floor space required, and is a desirable high-grade, high-efficiency unit for certain classes of work where these factors are important. It represents the highest development in large single-cylinder construction. An outline of one of these units is shown in Fig. 2.

An outline of a 30 000 kw, tandem-compound, 60 cycle unit, operating at 1200 r.p.m., driving a single generator, is shown in Fig. 3. The high-pressure element is

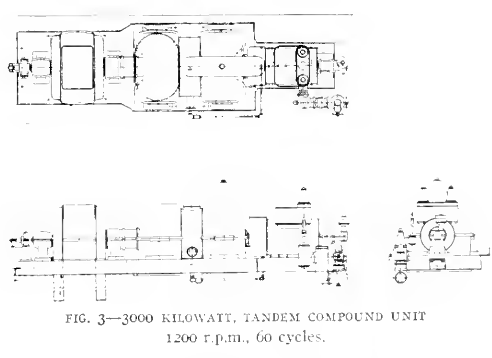

FIG. 3—3000 KILOWATT, TANDEM COMPOUND UNIT 1200 r.p.m., 60 cycles.

single flow, and the low pressure is semi-double flow. The blading of the two elements is arranged so that approximately one-third of the expansion takes place in the high-pressure cylinder and two-thirds in the low pressure. With the division made at this point, the

*For detailed description see the JOURNAL for June, 1915, p. 271.

pressure between the high-pressure and low-pressure elements varies from about 30 pounds absolute to about 45 pounds absolute. With these pressures the specific volume of the steam is such that the interconnecting pipe may be made comparatively small. The tandem type of machine has the advantage over the cross-compound arrangement of less weight and consequently lower cost; it has the disadvantage of "all the eggs being in one basket," that is, in case of accident to the generator or low-pressure element the whole unit is out of service. In case of accident to the high-pressure element it could be disconnected, or the rotor removed and the low-pressure element operated, if necessary, up to the full capacity of the generator, using high-pressure steam direct in the low-pressure cylinder, the governing being done by other machines in the system with which this unit would be paralleled. In the cross-compound arrangement there are two separate cylinders, each with its own generator, so that either element may, in emergencies, be operated to the full capacity of its generator while the other is undergoing inspection or repairs.

In the tandem construction, both high-pressure and low-pressure elements must of necessity operate at the same speed, which sometimes prevents obtaining quite as high efficiencies as are attainable with the cross-compound arrangement.

40 000 KW UNITS

The outline of a 40 000 kw cross-compound unit, the high-pressure element operating at 1800 r.p.m. and the low pressure at 1200 r.p.m., driving separate 60 cycle generators of equal capacity, is shown in Fig. 4. The high-pressure element is single flow and the low-pressure element purely double flow. In this unit the interconnecting pipe is placed overhead in order to leave the

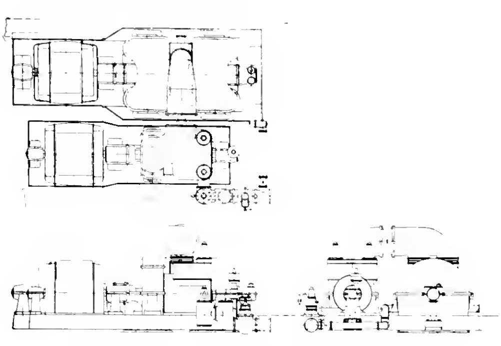

FIG. 4—4000 KILOWATT, 60 CYCLE, TWO-CYLINDER, CROSS-COMPOUND UNIT
High-pressure cylinder, 1800 r.p.m.; low-pressure cylinder, 1200 r.p.m.

entire space underneath the floor for the condensers. The pressure of the steam between cylinders varies from 12 to 16 pounds absolute. The interconnecting pipe must, therefore, be quite large. The gate valve in this line midway between the two cylinders is clearly shown. This valve may be closed at any time and either element operated alone, at relatively poor efficiency, however, while the other element may be disconnected and partially or wholly disassembled. The atmospheric exhaust for the high-pressure element is made in the bottom of the cylinder and passes out underneath the high-pressure element.

60 000 TO 70 000 KW UNITS

An outline of a 60 000-70 000 kw three-cylinder, two-stage unit, consisting of one high-pressure element

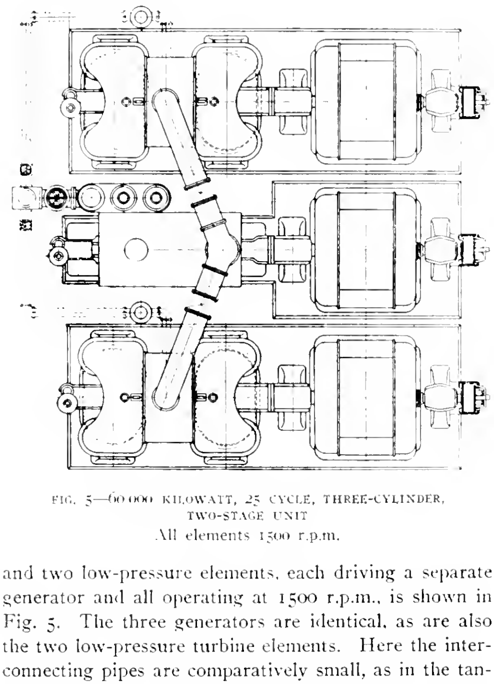

FIG. 5—60 000 KILOWATT, 25 CYCLE, THREE-CYLINDER, TWO-STAGE UNIT
All elements 1500 r.p.m.

and two low-pressure elements, each driving a separate generator and all operating at 1500 r.p.m., is shown in Fig. 5. The three generators are identical, as are also the two low-pressure turbine elements. Here the interconnecting pipes are comparatively small, as in the tandem-compound arrangement, and the valves in these pipes are arranged exactly like in the 40 000 kw cross-compound unit, and are used for the same purpose. The intermediate pressure is about the same as with the tandem-compound arrangement, i. e., 30 to 45 pounds absolute. No atmospheric exhaust is provided on the high-pressure element, as no emergency should ever arise in a station large enough to employ such a unit in which it would be necessary to operate the high-pressure element alone at the extremely poor efficiency obtainable when so operating. However, the high-pressure element may be operated with either one of the low-pressure elements up to the maximum capacity of the low-pressure generator, with efficiency only slightly poorer than the whole unit at the same load, or by closing the two valves in the interconnecting pipes the high-pressure element can be isolated entirely and both low-pressure elements operated on high-pressure steam direct up to the full capacity of their generators, or even to whatever overloads these generators will stand, the efficiency when so operated being only slightly poorer than when

operating with the high-pressure and one low-pressure element. To facilitate operation of the low-pressure elements alone, each is provided with its own governor and inlet valve, controlling the high-pressure steam admission to it. These governors and valves are so arranged that when normally operating in connection with the high-pressure element the valves will be closed and the governors thrown out of control, the governing for

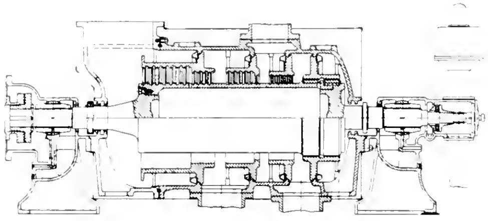

FIG. 6—LONGITUDINAL SECTION OF A TYPICAL HIGH-PRESSURE ELEMENT

the whole unit being done by the high-pressure element.

For units of 50 000 kw and larger this three-cylinder arrangement has many admirable features which should insure its wide adoption. The principal ones are:—

Extremely High Degree of Reliability—Although the capacity of the unit is large, the structures of the elements are comparatively small, and known safe factors of design need not be exceeded in either turbine or generators. Because of its extreme flexibility and the low temperature range in any one cylinder, it is superior in reliabilty to three separate units operating in parallel, each of one-third its capacity.

The efficiency is equal to or higher than that obtainable with any other known arrangement.

The cost per kilowatt is less than that of either smaller separate units or of single or double-cylinder units of slower speed and, therefore, necessarily greater weight.

In all of the turbines described of 30 000 kw and larger, the reaction type of blading, as originated by Sir Charles A. Parsons, is used throughout. Turbines of these larger sizes are usually built to order, that is, they are designed and built to meet the specific requirements of their purchasers. This is entirely feasible, for the reason that the costs of drawings and patterns are such a small percent of the cost of the unit that alterations or even new designs are justified for comparatively minor special conditions. This applies especially to overload capacities, the turbines being designed to have their point of best efficiency at the load at which they will normally operate, and with overload capacity above this sufficient to meet the maximum requirements.

A cross-sectional view of a typical high-pressure element and of a typical semi-double-flow, low-pressure element are shown in Figs. 6 and 7. These elements are of much the same design, whether arranged as tandem-compound, two-cylinder cross-compound, or three-cylinder compound. The high-pressure cylinder and its blade-carrying elements are made entirely of cast steel on account of the high steam pressures and temperatures which they must withstand. In all of the two-cylinder, cross-compound units which have as yet been designed, the high-pressure element has been provided with a few more rows of blading and the low-pressure with a few less, the low-pressure element being of the straight double-flow type; but the only reason for doing this has been to keep the generators of equal capacity, which is not usually important. No matter what the arrangement, the unit is normally operated exactly as if it were a single-cylinder machine. The generators are normally permanently connected in parallel (switches being provided for cutting out either element when desired). The condenser or condensers are first started up and a vacuum established in the turbines, the oil is put in circulation, a field charge is put on the generators, the engineer opening the throttle on the high-pressure element starts the unit up and brings it up to speed, the generator elements all the while being held in synchronism by the exciter fields. The switchboard operator then synchronizes the unit with the busses and connects it to the line. There is no synchronizing of elements with each other; in fact, there need be only one set of leads run to the switchboard for the whole unit.

ADVANCES IN RELIABILITY

The highest possible degree of reliability or serviceability in a turbine set is of the greatest importance. Absolutely continuous and uninterrupted service is being universally demanded, and it has become a matter of pride among public service electric companies to be able to maintain clean records in this respect on all of their circuits. To accomplish this result a sufficient number of units are kept in service to take care of any emergency. The degree of reliability of the units operating is, therefore, a measure of the amount of capacity in generating units, in excess of the maximum demand on the station, which must be maintained. It is also a measure, to some extent, of the load factor which may

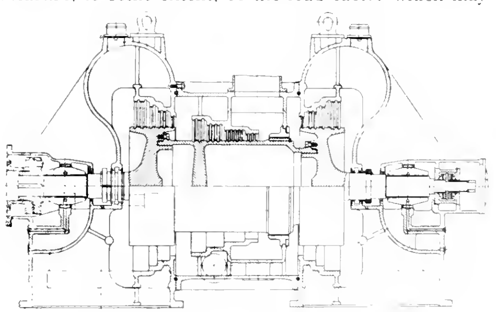

FIG. 7—LONGITUDINAL SECTION OF A TYPICAL LOW-PRESSURE ELEMENT

be carried on the units operating, with a given degree of reliability.

While the degree of reliability of turbogenerator units has been steadily increasing and is at present very high, the increase has not been due entirely to any one or few particular accomplishments. It has been brought about chiefly by these important factors:—

1—By adhering rigidly to the use only of known safe and reliable materials and known safe stresses.

2—By a great number of minor detail improvements and simplifications, many of which were made purely to better enable attendants to understand the function of the various parts, and to facilitate keeping them in proper normal condition.

3—By education and special training in the various classes of work of the entire human element entering into the manufacture and operation of the apparatus. A very large percentage of accidents experienced in former years were due directly to what are well known now as very obvious errors. These errors and oversights have been made (a) by the men engaged on designs; (b) by the men engaged in the manufacture and assembly of the machines; (c) by the erecting engineers who are responsible for the proper installation of the apparatus in the purchaser's power house, starting it in proper operation, and instructing the power house attendants as to the proper handling and maintainance; (d) the operating engineers and attendants who are responsible for proper operation of the machinery, as well as for maintaining it in proper operating condition. The percentage of these errors have been least with those in close touch with the designer and greatest with those farthest away from him.

ADVANCES IN EFFICIENCY

While very great reductions in steam consumption per kw-hr. have been effected since the first introduction of steam turbines in this country, the actual increase in efficiency of turbine blading has been very slight. The steam consumption of present-day turbines of the same capacities and rotative speeds as the first turbines built are less than five percent higher in efficiency, and in recent years no material increase has been possible. Reductions in steam consumption from approximately 22 lbs. per kw-hr. to less than one-half that amount have been due almost entirely to two factors, namely, changes in operating conditions, and increase in capacity of units for given rotative speeds. The steam pressure, superheat and vacuum under which a turbine must operate are conditions entirely external to the turbine and determine the design of the turbine, just as in a water power installation where the height of waterfall is fixed and the water turbine must be designed to develop the greatest possible amount of power from a given amount of water with that fall.

Due to advances in boiler construction, steam pressures have been steadily increased from 125 or 150 lbs.

TABLE I—EFFECT OF INCREASED STEAM PRESSURES

Increasing steam pressure from	Increases heat supplied to steam approximately	Resulting decrease in steam consumption approximately
100 to 150 lbs.	0.5 percent	8. percent
150 to 200 lbs.	0.35 "	4. "
200 to 250 lbs.	0.25 "	2.75 "
250 to 300 lbs.	0.2 "	2.25 "

gage to 200 and 225 lbs. gage. There is at present at least one station now under construction which is to employ 300 lbs. steam pressure, and others to use 500 and 600 lbs. are being seriously considered. The effect of increasing steam pressures is to increase the amount of heat which must be added to the steam by a very slight percentage, but to decrease the steam consumption rate of the turbine a considerably greater percentage, as shown in Table I.

In recent practice boilers are designed to superheat the steam from 100 to 200 degrees F. The addition of 100 degrees superheat increases the heat which must be supplied to the steam approximately five percent, but decreases the steam consumption rate of the turbine nearly ten percent; while 200 degrees superheat requires an increase of nine percent of heat supplied, but reduces the steam consumption approximately seventeen percent.

TABLE II—EFFECT OF INCREASE OF VACUUM

Increase in vacuum.	Decreases steam consumption of turbine approximately.
26 to 27 inches	4 percent
27 to 28 "	5 "
28 to 29 "	7 "

Due to advance in condenser construction, the vacuum available at the turbine has increased from 26 and 27 inches mercury to 29 inches (referred to 30 inches barometer), or has reduced the pressure per square inch at the turbine exhaust from two pounds absolute to less than one-half pound absolute. This has not required any additional heat, except as may have been caused by a slight increase of power required to drive the condenser pumps; but has effected reductions in steam consumption of the turbine approximately as in Table II. Further improvement in operating conditions will be made from time to time until a condition of equilibrium is reached where the decrease in steam consumption will no longer justify the increase required.

SUMMARY

During the past four years the maximum capacities of steam turbine units has increased from 15 000 kw to 70 000 kw. Units of still larger size are practical and will naturally result with further growth of the electric power industry.

Single-cylinder, complete-expansion units have been designed in sizes as high as 30 000 kw. However, at this rating, multi-cylinder units have predominated, and for the larger ratings they have been used exclusively, because of their higher degree of reliability as obtained by keeping the structures small enough to employ known safe factors of design; by reduction of temperature difference existing in any one cylinder; by the flexibility of the unit, enabling the remaining elements to be operated while any one is out for inspection or repairs, and because of their lower cost per kilowatt.

Advances in reliability have been accomplished by adhering rigidly to the use only of known reliable materials and known safe stresses, by improvements in detail design, and by reason of a higher training of the human element as obtained by longer experience in the art.

Advances in efficiency have resulted chiefly from improved operating conditions as resulting from improvements in boiler and condenser construction, and from increase of capacity of units for given rotative speeds.

Brushes for Commutators and Slip Rings

THEIR SELECTION, APPLICATION AND CARE

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THE nearly universal adoption of commutating poles, together with increasing commutator speeds and increasing brush densities, has made the problems of producing and selecting proper brushes for commutators and slip rings of importance of the first magnitude. That this is recognized by the makers of brushes, as well as by the users of their products, is suggested by the following excerpts from the literature of a few of the prominent brush manufacturers. The first, of historical value only, is as follows:—

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"Carbon brushes were * * * brought to the attention of the electrical profession in 1889." However, "It was not until * * * 1893 that this then radical departure in brush design met with any degree of success."

The second, not without justification, relegates excessive theory to the scrap heap in the following statement:—

"Abstract knowledge based on theoretical considerations offers little assistance in the solution of brush problems."

A third credits electrical men with a growing appreciation of the brush problem, which it is hoped has not been too generously bestowed. To quote:—

"Electrical men are realizing more and more the fact that brushes are not merely adjuncts but highly important factors in the successful operation of motors and generators."

The last reverts tersely to the past and near past; touches the present, and leaves to the imagination the possibilities of the future, in the following words:—

"The manufacture of carbon brushes was not perfected fifteen years ago. It has improved wonderfully in the last five years. The past two years have shown phenomenal progress."

From the foregoing it is evident that those most intimately informed in the art of brushmaking find the manufacture and prescribing of brushes studied and, in many instances, enigmatical problems. It is not surprising, therefore, that manufacturers of electrical apparatus, and operators of their product, experience difficulties in the selection, application and care of brushes for their varied equipment.

BRUSH COMPOSITION

Brushes are composed principally of:—

Carbon,
Carbon and graphite,
Graphite (natural),
Electro graphite,
Metal and graphite (metal-graphite),
Carbon and wire gauze,
Copper leaf.

Carbon is a non-metallic element found in all organic substances, and for commercial purposes in anthracite and other coals and in charcoal. The amorphous or uncrystallized form includes charcoal, coke, lampblack, etc.

Graphite (natural), also known as black lead and plumbago, is a crystalline form of carbon. It is found in many forms and is widely distributed, Ceylon being perhaps the chief source of that used in commerce.

Electro graphite (artificial graphite) is prepared commercially by heating coke (or other amorphous carbon) in an electric furnace and converting it from the non-graphitic to the graphitic state.

Combinations of carbon, carbon and graphite, graphite, and in some instances pulverized copper, are mixed with, or without, abrasives and binders, extruded or pressed into shapes varying from the size of the finished brush, to blocks and slabs of many forms and dimensions, which are baked or burned for use as brushes. The blocks and slabs are subsequently sawed and ground into sizes to suit the market demands. Brushes may be ground to almost any shape and can be furnished in block shape, bare or copper coated, drilled for, or fitted with, shunts, milled to the angle or radius to fit the commutator or rings, fitted with caps to protect the tops from the pressure springs and, if desired, equipped with almost any supplied or specified brush-lifting clips or devices.

The baking of the brush material is subject to many of the difficulties encountered in baking or firing earthenware. It is well known that a large piece of crockery or earthenware is more difficult to produce than a small piece, the reason being that there is more material and, consequently, more likelihood of warping, cracking, etc., from uneven burning or firing. The same troubles occur with brush material. It is obvious, therefore, that brushes made from small blocks, bricks or slabs or carbon are more likely to prove uniformly good, or homogeneous, than brushes made from larger sizes of the same materials and mixings.

"CAPPING" AND "COATING" BRUSHES

Soft brushes require protection from the wearing effect of the tension spring hammer. This protection consists of a metal cap which may cover the entire top of the brush, or merely that part upon which the spring presses. It frequently happens that the resistance between the brush and holder is less than that between the brush and shunt. As a consequence, the function of the shunt is usurped by the holder and the tension spring, resulting in the burning of the brush sides and in the

destruction of the spring. This indicates that the cap should be integral with or attached to the shunt, or that the shunt attachment is defective. The definite way to preclude this too frequent possibility is to devise means to cause the shunt to perform the function of carrying the total, or substantially the total current handled by the brush. Fundamentally, such a means is in no sense an impossibility, and sooner or later will, no doubt, be put into practical form. The sooner, the better.

If the shunts perform their function properly there is no electrical reason for copper coating the brushes (unless it be immediately under the shunt, for the purpose of improving the contact between the shunt and brush), and less reason for the subsequent tinning of the copper. In case the brush is soft, or mechanically weak, it is desirable to protect it from mechanical shocks, and from wear due to rubbing against the sides of the holders and against the brush tension springs. For this purpose a copper or tinned copper coating is desirable.

TERMS USED IN CONNECTION WITH BRUSHES

The following explanations of a few of the more important terms used in connection with brushes may prove instructive:—

Cantact Drop refers to the drop between the brush and the commutator. The contact drop differs with different materials, different brush pressures and different loads. For a given material and given load the contact drop decreases with increased pressure and increases with the load. It varies but little with changes in speed above 2500 feet per minute, and but little with temperature changes under normal conditions. Presupposing that the brush and spring pressures are identical, the contact drop between the commutator and positive brush differs from that between the negative brush and commutator on any given machine.

Brush Friction—The coefficient of friction depends upon the brush material, brush angle and commutator speed. With a given material and brush angle, the coefficient of friction increases with load and brush pressure and, generally speaking, decreases with increased commutator speed. Increased temperatures, in actual practice, justify the conclusion that the friction coefficient increases with increased temperatures.

Specific Resistance—The ohmic resistance of a cube having one-inch sides.

The Current Density (or carrying capacity) of a brush is based on its maximum continuous current capacity per square inch, without glowing, honeycombing, undue heating or sparking.

Glowing—A brush is said to "glow" when it becomes red or incandescent in spots in proximity with the commutator. This is due to the short-circuiting current under the brush, or to the short-circuiting current in combination with the working or kilowatt current. It may also be due to a lack of homogeneity of the brush (hard or soft spots of the same or different materials having characteristics foreign to the material in the body of the brush); to incorrect brush position; to improper brush selection; to selective commutation; to the brush covering too many bars; to high mica; to the machine having inherently poor commutating characteristics due to improperly shaped or spaced main poles or commutating poles; to bad commutating pole adjustments, or to a poor distribution of the armature windings. In the event the glowing cannot be stopped by correcting such of the brush or mechanical troubles as may exist; or by shifting the brushes, or readjusting the commutating poles, or both; a brush having higher current density values and less susceptible to the effects of high voltages between the commutator bars should be installed. If a suitable brush cannot be had, the design of the machine itself may be subject to modification.

Honeycombing—When brushes gradually burn away, forming small craters in their faces, they are said to "honeycomb." This is due to continuous sparking of a more or less hidden nature and may be either a slow or rapid nature. If the growth is slow, it is sometimes possible to correct it by increasing the brush pressure, thereby decreasing the contact drop and the contact arcing, and at the same time increasing the abrasive effect of the brush and grinding away the minute craters as they form. Honeycombing is due to the same causes, on a reduced scale, as glowing, and at times both may take place simultaneously on the same machine. Honeycombing has been traced directly to high mica, in combination with loose commutators; also to improperly spaced main poles; and unequal air gaps; and in non-commutating-pole machines, to an abnormal shifting or distorting of the magnetic flux. The trouble is most frequently corrected by substituting a more highly refractory brush possessing abrasive characteristics.

Hardness—Brushes have widely varying physical densities—some being very hard, others very soft. Very hard brushes usually carry a large amount of abrasive and have a low current density or carrying capacity. The softer brushes are more highly graphitic, carry abrasive to a limited extent only and have a high current density. The hardness or scleroscope reading is, therefore, indicative to a limited degree of the character of the brush.

Brush Inertia has to do with the weight of the brush. The lighter the brush, the more readily will it follow the irregularities of the rotating element, and the more promptly will it respond to a given spring pressure. Again, the wearing on the commutator may not prove so great. If a light and a heavy brush prove equally satisfactory electrically on a machine, the lighter brush is preferable. If the materials from which brushes are made are heavy, it is advisable to have an increased number of small brushes, rather than a limited number of large brushes; also the spring pressures should be in excess of the pressures on lighter brushes having the same dimensions, and used for the same service.

Refractory—Any material which resists the ordinary methods of reduction is said to be refractory. A brush, therefore, which resists wholly, or to a marked degree,

high temperatures, such as the heat generated by an electric arc, is said to be highly refractory.

Peripheral Speed is the speed in feet per minute of the face of the commutator or slip ring. Peripheral speeds which vary greatly require brushes having different characteristics. Generally speaking, carbon brushes are not so suitable for high peripheral speeds as graphite brushes.

BRUSH SELECTION

In the selection of brushes for commutators and slip rings there are several important governing factors. Among those of ranking importance are the following:—

1—The brush should possess such characteristics as will enable it to carry the maximum current to be transmitted by it. This maximum current consists of two factors for either direct-current or alternating-current use, viz:—

a—The kilowatt, load or working current of the machine, whether direct or alternating.

b—The short-circuiting current between the bars being commutated in direct-current service, and the magnetizing currents due to power factors above or below unity in alternating-current service.

The kilowatt load or working current is readily measured or determined in terms of either direct current or alternating current and for alternating-current service the magnetizing, wattless or idle currents can also be definitely measured or calculated. The short-circuiting current under the brush, however, is a very indefinite factor and may have values ranging from approximately zero in a machine having ideal commutating characteristics to values in excess of the load or metered current in machines having poor commutating characteristics. Brushes, therefore, may be, and generally are, subjected to loads greatly in excess of the load, or kilowatt, current.

Anent the short-circuiting current under the brush:—A direct-current, non-commutating pole generator was designed for, and sold with, a given rating, the rating being in excess of the immediate demands. As the demands increased, armature temperatures became abnormal and commutating troubles expanded. It was impossible to commutate within many kilowatts of the name-plate rating. A local concern proposed to make the machine deliver its full-load rating for a given sum, with the further understanding that a bonus of so much per kilowatt was to be paid for each kilowatt output in excess of the machine's one hundred percent rated capacity. In the event of failure no money was to be paid. The proposition being accepted, several modifications were resorted to, the principal one being that of "trimming" or "beveling" the poles. In time the machine was groomed for the bonus; the test followed,—also a failure. The machine not only failed to deliver its full-load rating, but persisted in dangerous temperatures. A friendly engineer was consulted, who with a flight of surprising intelligence for a man of his profession, suggested that the brushes be slotted, parallel with the commutator bars, and to a depth of an inch or more. The output jumped; temperatures dropped; the repair concern collected its bill, plus a bonus, and the friendly engineer stood modestly by, with satisfaction for his portion. This is not a fanciful sketch, but a fact, and illustrates the unknown which is taking place to a greater or less degree under all commutating brushes.

2—The brush should be homogenous, i. e., it should be uniform in material, mixture and hardness (free from hard and soft spots.

3—Brushes for either alternating or direct-current use should be self-lubricating. Experience shows, however, that the vast majority of brushes require lubrication. In many instances brushes are "treated" by the makers, i. e., they are impregnated with certain lubricating oils, greases or compounds, in order to make them self-lubricating, or as nearly self-lubricating as possible. Generally speaking, the permanency of such treatment is problematical, inasmuch as the lubrication frequently volatilizes, or drains from the brushes, leaving the brush practically, if not entirely, in its dry state.

4—For undercut commutators the brush material should be entirely, or to a great degree, free of abrasive (that is, of certain cutting compounds or mixings which are added to the brush material to scour or polish), or the commutator will wear too fast, bridge the slots, necessitate frequent beveling of the bars, repeated undercutting and constant cleaning.

5—For smooth commutators with soft mica a larger percentage of abrasive is desirable than in brushes for undercut mica.

6—For smooth commutators with hard mica brushes should be highly abrasive. This usually means a decreased brush capacity and decreased lubricating values, although it is claimed for some brushes that proper abrasive effect is secured by hardening under enormous pressures, no abrasives being used.

7—For alternating current or slip rings the brushes should be as nearly self-lubricating as possible and should wear themselves rather than wear or cut the rings. These brushes may be of metal graphite composition or of a graphitic nature only. If of metal graphite they should not wear so as to form a continuous "fringe" or "wire edge" along the sides of the brushes at the rings, but should be of a mixture sufficiently granular to disintegrate and break away in small particles. The "fringe" or "wire edge" has been known to form and break away from the brush in full brush contact lengths, falling so as to bridge to adjacent rings and cause disastrous flash-overs.

DIRECT-CURRENT BRUSH APPLICATION

After selection, the success or failure of a brush may be directly due to its application. This may be traceable to the following causes:—

1—*The angle at which the brush is set.* It is true that certain types of machines which are subject to frequent reversals, such as mill motors and street railway motors, may be said to automatically fix the brush position as radial, or practically radial. In the case of railway motors this is perhaps the universal practice. This

does not mean, however, that if set at some angle, say 15 or 20 degrees, or even a greater angle, the average results might not be as good, if not better, than the radial setting. When machines are not subject to reversals, the proper angle will depend,—

a—Upon whether the rotation is against the toe or against the heel. (By "toe" is meant the *point* of the brush, or the side having the acute or small angle. The "heel" is, therefore, the side having the larger angle. This is independent of rotation). If against the toe, the angle may be as great as 35 degrees or more, but above 35 degrees the toe becomes very sharp and mechanically weak. This point, therefore, must be guarded against. If against the heel, the angle may be from 12 degrees to 25 degrees. In instances where the brush touches more bars than required the sharp toes can be beveled off, thereby reducing the brush contact and the short-circuiting current under the brush, and at the same time increasing the mechanical strength of the brush. Whether running against toe or heel, it is good practice to round off the sharp or knife edge of the toe. This reduces the possibility of the knife-like edges digging into the commutator in case the brushes jam or become tight in their holders, and at the same time protects against brush breakage.

b—Upon the friction coefficient of the brush. This factor is a decidedly variable one, being influenced not only by the inherent characteristics of the brush, but also by the glazing of the contact face of the brush, the varying brush temperatures due to load and spring pressure, and the condition of the commutator—whether smooth or undercut, hot or cold, or in good, poor or bad mechanical condition. As a rule, bad mechanical conditions can be eliminated by properly seasoning the commutators and keeping them practically round, smooth and free from high mica. The other influences, however, are permanent, although they may be, in a measure, modified by finding a more suitable brush angle.

2—*Brushholders*—Brushholders vary widely in design. There is no universal holder. If the commutator or slip ring speed is low, a holder having a sluggish spring and slow action will give entirely satisfactory results; such a holder on a high-speed machine may fail miserably. High speeds require quickness of action on the part of the brush. This means a sensitive quick-acting spring and a holder designed to aid the spring. A high-speed holder may give excellent results on low-speed machines; but a low-speed holder is not likely to approach even fair results on high-speed machines. Brushholders should be designed to meet specified conditions, not merely designed to cheapen manufacture. Money is intelligently and economically invested when invested in well-designed, capable holders, but utterly wasted when "soaked" in flimsy substitutes. Much depends upon the type of brushholder. Certain fundamental requirements are often too indifferently regarded. Brushholders must be stable, and should be built on lines conforming closely to the lines of the brush as it will appear when in service.

The *box*, or part holding the brush, should be as nearly a full box as possible. To accomplish this, the shunt attachment (and brush-lifting clips when used) must be flush with the face of the brush, and the pressure spring so designed as to give maximum brush wear without necessitating too great slotting or cutting away of the holder on the sides. Whether the rotation is against the toe or against the heel, both the toe and heel sides of the holders should have approximately equal areas for the support of the brushes. It is obvious that the shorter the box, the greater will be the shifting movement of the brush on the commutator due to looseness in the holder; and the deeper the box, the less will be the shifting. From this it follows that the boxes should not be too short, nor should the brushes be too loose in the boxes.

It is an established fact that with even very slight play in the holder the changing brush friction due to load, temperatures, etc., will result in a changing relation between the brush and the commutator, and thereby cause changing and misleading brush drops from day to day. This accounts for the difficulty in verifying, on different days, brush drops, although the loads may be identical. The neutral does not change, but the relation of brush contact to commutator does change, and the brush drops vary accordingly.

Another explanation for the changes which take place in brush drops is that when brushes have been freshly "sand-papered" or "ground in" the surfaces have unglazed or soft faces, the brush drops being influenced by the porous condition of the faces, and the lubricating values of the particles liberated during the time the brush face is seating itself to the commutator. During this period the commutation, with certain kinds of graphitized brushes, may be much better than after the glaze or permanent surface forms on the brush. Drops taken during this time may not be the same as drops taken after the brush is "faced up" and may prove seriously misleading. Definite or reasonably permanent drop values are, as a rule, to be had only after the brush faces have reached a fixed condition.

From the foregoing it is obvious that brushes should fit snugly, but not tightly, in the holders; also that there are certain relative dimensions which are preferable between the brushes and holders and which must not be ignored if the best results are to be obtained. For instance, the side of the holder in the direction of rotation should not have less area than the lagging side. In fact, the side against which the brush presses should have preferably a greater area than the opposite side—certainly not less area. With a limited area to oppose the brush, movement of the brush in the holder, due to looseness, oscillation and imperfect relations between the brush and commutator, accentuates the change in the angle of contact, and results in poor commutation, as well as in mechanical and electrical damage to that part of the brush in contact with the holder.

If a brush is thin its length and holder contact should be greater than if it is thick, for the reason that the

thinner the contact area on the commutator, the less stable will be the brush on the commutator, and the greater will be the need of support from its holder. To illustrate:—If the brush contact is a knife edge, serious chattering may result and there may be a maximum of instability, but if the knife edge be gradually removed the brush will become increasingly stable as the thickness of the brush contact increases, and if the brush angle is correct the maximum stability will be reached when the brush has its greatest thickness in contact with the commutator. It stands to reason, therefore, that the greater the area due to thickness, the more stable will be the brush on the commutator, regardless of the holder, and that as a consequence a holder for a thick brush might not prove at all suitable for a thin brush, the speeds being equal. If, however, there is the same amount of lost motion in the holders for a given length of thin brush and thick brush, and the brush angle is such that the thick brush moves its maximum in the holder, then the thick brush will show a greater change in its relation to the commutator than the thin brush. The thick brush, however, will not be so likely to shift its maximum shift on account of its bearing surface being greater than the bearing surface of the thin brush. In other words, it rests on a greater area.

3—*Brush pressure* depends upon the character of brush, the commutator speed in feet per minute, and the mechanical condition of the commutator. Broadly speaking, it varies from two to five pounds per square inch, the pressures generally used being from 2.5 to 3.5 pounds on commutators and from three to five pounds on slip rings. If there is a tendency for the commutator to burn, this can at times be corrected by increasing the pressure, and thereby increasing the abrasive effect of the brush sufficiently to scour out the burning and maintain a polished surface. When the mica is not undercut the brush should have sufficient abrasive effect not only to scour out possible burning of the commutator bars, but also to wear and keep the mica flush with the commutator bars.

Spring Balances or Scales—Much is heard of the use of scales or spring balances to determine brush pressure. The use of such devices may result in mental relief, but very few machines benefit on account of them. Unless all brushes are equally free in their holders the pull on the balances will differ, and unless the angle of pull is the same on each brush the results will differ. It is doubtful if any two men under the most favorable conditions would agree within reasonable limits as to the measured pressure, provided they were ignorant of the other's efforts. It is only with the most careful attention to details that measured brush pressures are to be depended upon. Again, the running pressure will vary more or less from the idle pressure, the reasons being obvious.

The above comments are not for the purpose of discrediting the use of scales or balances so much as to bring out the necessity for using them properly, if they are to be used at all.

4—*Mixing Brushes*—Brushes having different characteristics should not be mixed on the same arm. In rare instances the use of brushes of one type on all of the arms of a given polarity and of a different type on all of the arms of the opposite polarity is permissible. This application is desirable when both abrasive and lubricating action is required, or when the electrical characteristics under the brushes differ greatly on arms of opposite polarity, due to a lack of electrical or mechanical symmetry in the design of the machine. This lack of symmetry may be such as to result in brush drop variations between brushes of opposite polarities of sufficient importance to warrant the use of brushes having different characteristics on the opposite arms.

Again, there are machines on which graphite brushes for lubricating purposes may be installed to advantage. Such brushes should be spiraled around the commutator so as to cover the entire surface and at the same time keep the kilowatt output balanced as nearly as possible between the several arms. These brushes should not have shunts. The less electrical work they do, the greater will be their lubricating value.

There are also machines on which highly abrasive brushes (installed as indicated for the lubricating brushes) may be installed to advantage for the sole purpose or scouring or polishing the commutator and keeping the mica ground flush with the commutator bars.

5—*Staggering Brushes*—As a rule, it is good practice to stagger the brushes, that is, the brushes on the several arms should not trail, or cover the same section of the commutator. Staggering is done to cause the commutator to wear evenly, that is, to keep the commutator from ridging; and should be done, theoretically, in pairs of arms (not alternate arms), that is, one positive with one of its adjacent negative arms should trail, but the next pair of arms should be set, if possible, to the right or left of the initial pair, half the distance laterally between brush centers. The third pair should trail the first pair; the fourth, the second, and so on.

Bearing in mind that (in the case of a generator) the positive brush is negative to the commutator, and the negative brush positive to the commutator (the opposite being true in the case of the motor), and that the two polarities affect the commutator differently, it should at once be appreciated why, theoretically, alternate arms should not be staggered.

Ample evidence of the desirability of staggering in pairs is available. One proof, however, is sufficient here. Certain kinds of brushes pick up copper. If both positive and negative brushes pick up copper, it may be either a purely mechanical condition, or a combination of the mechanical with the electrical. If only one polarity picks copper it will be the positive brush, and is an electrical condition. This indicates that the positive brush has a greater wearing effect, due to electrolytic or kindred influences (such as is evidenced in the deposits resulting from other arcing, the "building up" being on the negative electrode), than the negative, and that if all positive brushes trail the commutator will wear, or tend

to wear, more seriously under them than under the negative brushes. Staggering in pairs equalizes this wear. It is, of course, understood that in the case of motors the opposite is true.

In view of the added shop complications in the manufacture of brushholder arms for staggering in pairs (requiring four standards of arms), as opposed to staggering alternately (requiring but two standards of arms), it has not been considered, practically speaking, worth while to adopt generally the four standards. There are, however, instances in which the theoretically correct method is desirable. Such cases are evidenced by abnormal wearing and ridging of the commutators. The present practice is, as a rule, to stagger alternate arms. There are isolated instances in which it is claimed that it is advantageous to have all the brushes trail, but results contradict this practice as being generally applicable.

6—*Selective Commutation*—There is but one direct-current machine in which the brushholder arms carry equal currents. Obviously, this is the bipolar or two-pole machine, or its equivalent, the four-pole machine having but two brushholder arms. Selective commutation exists between different arms to the same proportional extent that it exists between different individual brushes on individual arms. For this reason the spacing of the brush arms should be electrically correct; the brushes should be of one grade (at least for each polarity); the brush shunts should be identical, and the contact pressure uniform. It is at once possible to shift the load between different brushholder arms by increasing or decreasing the brush pressures, or in any other way increasing or decreasing the resistance in the circuit of any given arm. In short, keep the resistance of the circuits comprehended in the several arms as nearly balanced as possible.

CARE OF BRUSHES

Superficially, the care of brushes is simple enough, but, in fact, quite the contrary is true. Properly selected and applied brushes may fail on account of neglect, while improperly selected and applied brushes may render acceptable service if given intelligent care. Proper care of the brushes and brush rigging is a fundamental of good commutation, and of a prolonged life for both commutator and brushes. Operators of electrical apparatus are directly responsible for the majority of their commutating troubles, although the manufacturer is frequently held to account. There are, on the other hand, a few (a very few) who give such superior attention to their brushes that inherent brush and machine evils are rarely permitted to assert themselves. The following practices will more than justify the effort:—

1—Keep the brushes clean. Both direct and alternating-current brushes get dirty—become coated with carbon and copper dust, which packs between the brush and holder and jams or "freezes" the brush in the holder. This frequently results in broken brushes, a gouged commutator, or both, concluding with a "flat spot," and necessitating the grinding or turning of the commutator. The commutator is blamed; the brush did the damage; negligence was the cause.

2—Have the spring pressure uniform. Otherwise, the brushes will commutate unequal currents; overload some and underload others; overwork some shunts and underwork others; cause an excessive flow of current between the overloaded brush and holder, and brush and spring; burn the sides and tops of the brushes, and destroy the pressure springs. This unbalanced effect of brush work is sometimes known as "selective commutation"—not so descriptive a term perhaps as "unbalanced commutation," "unequal commutation," or possibly some other, which might have been selected. However, after the meaning of a term is understood, it matters very little what the spelling is.

3—Fit the brushes to the commutator properly, disregarding looks, and there is nothing "easy" about "grinding in" or "sandpapering" brushes. This apparently simple performance requires patience, care and judgment. Too much haphazard indifference is exercised in the seemingly simple act of making the brush face conform to the commutator surface. Examine indiscriminately the faces of the brushes on a few machines. The chances are that the brushes on nine out of ten of them will show imperfect brush contact surfaces; two or more contact faces may be clearly discernible on a single brush; one or more corners may be ground away; the heels or toes, or both, may be "nosed" off; or perhaps, worse still, the faces may show comparatively large areas of inactive surfaces. When "grinding in" brushes keep the sandpaper against the commutator. Do not allow it to "belly," "bow" or "buckle," unless convinced that cornerless, heelless, toeless, ball and cylinder faced brushes are the proper things. Knowledge of what is being done, and why, is necessary for most men if their interested efforts are to be expected. The average man if told why will learn how, but only a few learn both why and how for themselves.

When a new set of brushes is installed it is frequently possible to purchase in the local market sandpaper, or garnet paper, or their equivalents (these papers are made in rolls of 25 to 50 yards, or more), in any lengths required to go around a commutator. It should have a lap of several inches and be so mounted on the commutator as to preclude the lapped end butting against the brushes when the machine is rotated for grinding. With many commutators the friction between the commutator bars and sandpaper (if the paper is taut) will suffice to keep the paper from slipping, especially if, when starting, the paper is given a pull in the direction of rotation by the operator. If the paper persists in slipping use a little glue to stick the under end of the paper at the lap to the commutator. All traces of the glue must be removed from the bars before putting the machine into service.

A second method is to remove the middle brush on each arm and bind the paper to the commutator by running tape or string entirely around the periphery. If

necessary, also bind the paper at the inner and outer ends of the commutator.

After the paper is anchored the commutator may be rotated by hand, or in any convenient way. Great care must be exercised in "grinding in" brushes in this way, as the cutting is very rapid, especially with soft brushes, and much of the life of the brush may be ground away in a very few revolutions. If after the brushes have been surfaced in the above manner, the trailing edge shows a poor seat on account of having had to mount the ridge due to the lap in the paper, a final surfacing should be done with very fine sandpaper by hand. The foregoing method is particularly desirable when a machine has very hard brushes, or a large number of soft brushes. It is a great time-saver after the knack of applying and anchoring the paper is understood.

With slip rings, if carbon or graphite brushes are used, the same general scheme is applicable, but if metal graphite brushes are used, emery cloth, or its equivalent, is preferable.

There are those who advocate and those who practice pulling the grinding paper in the direction of rotation in order to more accurately surface the brush. This seems logical enough on first thought, but inasmuch as the commutator is not in motion when the brushes are surfaced in this manner there is no assurance that the brush will bear the same relation to its holder (and therefore to the commutator) when the commutator is rotating and, consequently, no assurance that the contact will remain fixed. This perhaps explains why brushes frequently show perfect contact when idle, but poor contact when in service. Generally speaking, this method of fitting the brushes, therefore, is not necessarily more dependable than other methods, though in proven instances it is to be commended.

4—It is important that the brushholders, whether for direct or alternating-current use, be neither too close to nor too far from the commutator or slip rings. A suitable distance is from three-sixteenths to one-quarter of an inch.

5—If the brushes are copper-coated, the coating should not be allowed to come in contact with the commutator or slip rings. This means that as the brushes wear the copper coating should be scraped back and not allowed to extend below the brushholder box. With proper shunts there should be no need for copper coating from an electrical standpoint, although for mechanical reasons it may be desirable as a protection for soft or structurally weak brushes.

6—If the toe of the brush is very sharp it is good practice to "nose off" the knife edge. This reduces breakage and militates against gouging into the commutator.

SHUNTS

The function of the shunt is to carry either the major part of the current collected, or all of it, preferably all of it. The ultimate of shunt application is a combination of brush, shunt and terminal, which will cause the shunt to carry the maximum current required between the brush and machine terminals; and until this consummation is realized manufacturers and users of electrical apparatus must expect to pay liberally, not only for damage to their brushes caused by the current by-passing the shunt, but also for frequent damage to their brushholders and brush pressure springs.

Shunts of today are made of many hair-like strands of loosely twisted, braided, woven or plaited copper, the object being to secure the maximum flexibility consistent with mechanical strength and current-carrying capacity, current-carrying capacity being of first importance. The size and number of shunts for each brush is governed by the current to be carried, the mechanical strength required, and the type of brushes and holders to be equipped. There may be from one to four, or even more, shunts per brush. If shunts are to be subjected to the effects of chlorine or other deteriorating gases they may be protected by a "tinning" process, which in no wise affects their flexibility. This is of particular value to chemical plants operating electrical apparatus. Shunts are attached to brushes in a few acceptable and in numerous nefarious ways; but, in general, two distinct methods are practical:—

a—Assembled with terminals independent of the brush and bolted or screwed to the brush. Shunts made in this way can be attached or unattached at will and used on one or more sets of brushes, and can be readily replaced if damaged or broken. The contact between the brushes and shunts, however, is likely to vary greatly and selective commutation result. With low density and cheap brushes this type of shunt was desirable, for the reason that the cost of the shunt frequently equaled that of the brush. This relationship, however (except in the case of special and very small brushes), has practically ceased to exist. At the present time the cost of the shunt is relatively small, compared to the cost of high-density brushes and, in view of the electrical and mechanical disadvantages of the independent shunts, they are not to be encouraged.

b—Assembled and attached to the brushes permanently by means of spun rivets, with and without solder; bolts or screws with nuts, with and without solder; threaded cylinders welded to the shunts and riveted at the ends; and shunts cemented or packed in holes drilled in the brush. Unless the shunt is soldered or welded to the bolt or cylinder, the contact is not more dependable than with the independent shunt, and unless the bolt or cylinder is threaded and has a thread fit through the carbon, the surface contact may not remain good throughout the life of the brush. A threaded through device, when bolted or riveted at the ends, cannot turn in the brush without stripping the threads, whereas a smooth bolt or cylinder has no positive anchorage except at the ends.

The practice of "tinning" the shunt connections to the brush (and also the copper brush coating) is commendable except in cases where the brush or shunt temperatures are likely to exceed the melting point of the tin or solder. Perhaps the simplest form of shunt at-

tachment is that in which the shunt is inserted in holes drilled in the brush and packed or cemented in with a metal cement. When such attachments can be made mechanically dependable, and as good electrically as the better types of the more expensive methods, it would seem to offer superior advantages. The opposite end of the shunt, that is, the machine or brushholder end, is usually regarded with more or less indifference and is treated in the same general way by all shunt builders. The details of the terminals attached to these ends vary but little in form or method. In fact, the sphere of variation is self-limiting. However, there is immediate opportunity for at least two betterments, viz., these terminals should, first, be made heavier; and second, be more definitely attached.

In brief, shunts should have capacities for the maximum demands on the brush. They should have maximum flexibility consistent with mechanical strength. They should be attached to the brush with due regard for both the electrical and mechanical requirements. They should have terminals electrically and mechanically sufficient for properly attaching to the brushholders or brushholder arms. Shunt care comprehends the maintenance of proper connection between the shunt and brush, and between the shunt and brushholder or brushholder arm, as well as the maintenance of the flexible itself. Shunts frequently break due to vibration from excessive brush chattering. Replace broken shunts with new or repaired ones, or with a new brush and shunt complete.

Brushes have been condemned, only to find the shunts at fault. Two identical machines equipped with identical brushes gave seriously contradictory results. The equipment differed in the single detail of brush shunts. The brushmaker had, in one case, furnished the brushes with shunts attached. The machine equipped with these brushes gave excellent results. The second machine was equipped with the same brush, but with an independent type of shunt. Its performance was deplorable. Investigation resulted in many theoristic "whys" and "wherefores," but no "reasons," until with milk and water enthusiasm it was decided to interchange the brushes on the machines. The performances of the machines were immediately reversed. Both machines now have, not only identical brushes, but identical shunts, and give identical service. A little thing like a shunt may prove the barrier between failure and success. The shunt should be large enough to perform its function and kept in shape to perform it. Unless in case of emergency, different types of shunts on identical brushes should not be used on the same brushholder arm, nor should different brushes with identical shunts be so used.

All arms of a given polarity may be equipped with shunts or brushes different from those on the arms of opposite polarity; but no mixing should be practiced on individual arms, or on less than all the arms of a given polarity. Mixing of shunts or brushes, or both, results in selective or erratic commutation, thereby overloading some and underloading other brush units. Mixing of brushes or shunts is rarely justifiable, although in isolated instances the fully equipping of opposite polarities with brushes having different characteristics has proven efficacious.

CARE OF COMMUTATORS AND SLIP RINGS

The care of commutators and slip rings is so closely related to the care of brushes that a few pertinent requirements may be regarded as applicable here:—

1—Keep the commutators and rings clean. When in service use a dry canvas or some related cloth having a hard texture. When soft, "nappy" materials are used the "nap" is caught by the slots or rough spots and pulled under the brushes, where it lodges and helps to collect and hold dirt and carbon. When shutting a machine down it is good practice in most cases to clean the commutator with a little gasoline on a hard surfaced material. This not only removes any grease or oil from the commutator, but also frequently improves the brush condition by removing from their faces the residue of greases or oils collected by them.

2—If the mica is flush, see that it is kept flush. If holes appear in the mica, clean them thoroughly and fill them with a dependable filler. Dental cement is perhaps as desirable for this purpose as anything to be had at the present time. These holes are generally traceable to the too free use of lubricating oils, many of which attack the shellac in the mica and rob the mica of its binder. This trouble in its incipiency is of very slow growth, but later increases rapidly, due to the increasing amount of carbon, copper and other dust which collects in the holes and enlarges the burning area subject to the short-circuits which take place between the bars.

3—If the mica is undercut or recessed, keep the slots clean. For this purpose the use of fiber, bone, horn or hardwood is more desirable than metal, for the reason that metal is likely to cut the mica and deepen the slots. The advantage of deep slots are all disadvantages. Both practically and theoretically, mica need be but a hair's breadth below the surface to accomplish the end desired. The shallower the slot, the better. Depth encourages the collection of carbon, copper, dirt, etc., and is responsible for the bridging of the slots, which necessitates the beveling of the commutator bars.

4—Keep the edges of the commutator bars beveled or chamfered. When slots are deep (as most slots unfortunately and unnecessarily are) the commutator bars pull, or drag over, especially on the lagging edges of the bars. Unless the edges are beveled this pulled-over edge will, in time, close or bridge the slots and cause "flash overs;" also melted-out connections between the necks of the commutators and windings, and even burned-out armature windings. These things not only may happen, but have happened.

5—Keep the necks of the commutator clean. Dirt between the necks is not only bad for the commutator, but affects adversely the ventilation and, therefore, the temperature of the machine.

6—If the machine "flashes over" shut it down and remove all blisters or burned spots; otherwise the brushes will be unnecessarily worn away, and the commutation will be imperfect.

7—In the matter of slip rings, keep them clean, including studs, spider (or bushing), leads to armature windings, brackets or supports for brushholder yokes, and all insulation between the several parts.

LUBRICATION

The necessity for lubricating brushes, or commutators, exists, regardless of all claims to the contrary. It is realized that the possible hazard to the machine, together with the "Safety First" campaign (or more properly, the legally imposed liability responsibilities of the employers), is an incentive to increased caution in the handling of machines, and that this involves, among other things, the use of self-lubricating brushes. It is doubtful, however, if the apparatus is as well groomed when avoided or ignored as when receiving frequent visits from the attendants. As a consequence, the chances for accidents to both apparatus and men may be increased rather than diminished on account of the failure to detect and correct irregularities in advance, as opposed to rebuilding after a smash-up. On rare occasions, the ideal combination of commutator and brush is found, which requires no lubrication, but such "finds" are the exception. However, the self-lubricating brush is more nearly an accomplishment today than ever before, and sooner or later its realization may at least be hoped for. If brushes operate without lubrication it is a cause for congratulation. If brushes require occasional lubricating it should be regarded as an entirely normal condition.

What lubricant is most effective is a much-argued subject. There are many lubricating compounds on the market, the values of which depend largely upon the individual opinions of those who use them.

Paraffine—If the commutator reaches a temperature high enough to melt paraffine it will prove as efficacious, perhaps, as any lubricant to be found. This applies to either smooth or undercut commutators. Paraffine is not recommended for commutators or brushes which run at low temperatures, for the reason that it "gums" the brushes and brush rigging, veneers the commutator, fills the slots, and collects dirt and dust. Paraffine should be applied quickly and sparingly. Before administering paraffine (or any lubricant) the commutator should be cleaned with a dry cloth. This practice precludes, to a marked degree, the accumulation of grease, carbon and copper dust, etc., and is recommended, regardless of the lubricant used.

Kerosene, or coal oil, should be used sparingly. It is very penetrating, and in time will eat into the shellac or binder of the mica segments, forming "holes," which, unless properly filled, will invite serious consequences, involving even the rebuilding of the commutator. There are other oils which act in the same way, but not so quickly.

Gasoline has little or no lubricating value. However, it is an instantaneous cleanser, and by removing dirt and grease from the commutator and brushes frequently, improves commutation. It is not entirely safe for use on a loaded or sparking machine, for the reason that it is sometimes ignited by the arcs which form between the bars and under the brushes, and burns or confuses the attendant.

If *vaseline* is used it should first be melted and applied to a cloth; otherwise it will gum, stick and prove more troublesome than paraffine on a cold commutator.

Light engine and dynamo oils are frequently used with good results, but they should not be too freely applied. Frequent application is more desirable than too free application.

There are many commutators on which a clean, dry cloth will prove as effective, temporarily, as lubrication; that is, a commutator may need frequent cleaning, but not necessarily frequent lubricating. This is sometimes due to the unfortunate habit certain types of brushes possess of liberating abnormal amounts of carbon dust, much of which adheres to the commutator. *This dust should be wiped off—not stuck on.*

There are among brushes a few that are sufficiently self-lubricating to be ignored after being put on the machines. Experience shows that some of these (cost considered) have comparatively short lives. It is not improbable that the occasional lubricating of these brushes would extend their usefulness appreciably and more than justify the already-paid-for time and energy involved in giving them the limited amount of assistance they require.

Whatever benefits are derived from any source, *brushes included*, must be paid for in certain combinations of time, material, energy and cash. It is clearly up to the users of brushes to choose their own combinations, profit by the combinations of others, or accept what comes their way uncomplainingly.

BRUSHES FOR SLIP RINGS

The copper leaf brush for slip rings, which has been in favor since the days of incipient machines, is fast giving way to "block" or "metal graphite" brushes. Generally speaking, metal graphite brushes consist of various mixings of pulverized copper and other metals with graphite, shaped under pressure. When metal graphite brushes were first introduced their carrying capacities were greatly over-estimated. Manufacturers of electrical apparatus dropped into the error of using too few brushes, and in many instances found it necessary to increase the slip ring brush equipment as much as fifty percent before satisfactory results could be obtained in the field. At the present time the maximum permissible current is considerably below 150 amperes per square inch, while the sane limit is perhaps under 125 ampers per square inch. This type of brush is also used on direct-current machines of very low voltages. Its metallic characteristics, however, are at times hard on the commutators.

As a rule, the more highly graphitized brushes have proven the more satisfactory in that they have a longer life and cut the rings less. It is contended that these brushes are self-lubricating, and to a degree this is true. However, if the rings on which they run are kept free from copper dust, and a slight amount of lubrication (light oil) is judiciously applied, the life of both brushes and rings will in most cases be prolonged. This type of brush is extremely heavy and requires a brushholder of decided stability, with springs capable of pressures as high as five or more pounds per square inch. The actual pressure to be used is determined by the type of ring, speed of ring, and composition of the brush. It is, however, rarely less than three and one-half pounds per square inch, and more frequently five. When brushes of this type are allowed to spark they disintegrate rapidly and the life is greatly shortened.

In case the brush is not sufficiently granular in texture it will "roll up" or "fringe" or form "wire edges" on the sides. Obviously, such brushes are dangerous, for the reason that such edges frequently break away from the brush in full contact length, bridge to, or fall across, rings having different polarities, and flash the machine. To guard against this the brush should be slotted radially with a file, two slots to a side "V" shaped, and about one-eighth of an inch in depth. Under this condition the maximum possible length of thrown-off metal will be something less than one-third of the arc of the brush contact. This is too short to bridge or cause damage. Although a brush may be in every other way satisfactory, if it has this "fringing" characteristic it is not desirable.

As a means to an end, the "metal graphite" brush may be regarded as admirable, but as a permanent institution it has to contend with such characteristics as:—

1—Its cost, so far, has proven high.

2—It has excessive weight.

3—Its useful percentage of wear is low compared to its first cost.

4—It wears the rings excessively, unless studiously attended.

5—It requires a perfection of ring not required by other brushes.

Its advantages are:—

1—Low brush drop (but not lower than copper leaf).

2—Perhaps less ring wear than copper-leaf brushes.

In view of the doubtful virtues of the metal graphite brush, the apparently logical solution of the slip ring brush problem is the development of a graphite, or related, brush suitable for the purpose. Some of the advantages of such a brush, if developed, should be:—

1—Reduced first cost of brushes.

2—Reduced wear on rings.

3—Increased cleanliness of rings and brush rigging due to such particles of graphite as are liberated being blown away. (The metal particles from the metal graphite brushes settle more entirely on the machine).

4—Increased brush life.

5—Advantages of low brush inertia.

As opposed to the advantages, there are the improbable disadvantages of:—

1—Possible increased losses in brush drop between brush and rings—a theoretical possibility of moment perhaps on account of decreased efficeincy of a small fraction of a percent, but in reality a very doubtful loss, on account of the great difference in brush inertia, and the highly variable conditions under which brushes operate in actual service.

2—Initial expense connected with adding more holders. It will be claimed that extra holders may not be readily added to the present type of brushholder supports. This is not a serious negative for the reason that supports have been designed and can be designed to entirely encircle the rings, and thereby increase the brush mounting capacity in excess of 50 percent. A second way is, in the case of new machines, to widen the rings.

From the above it would seem that a careful analysis of the possibilities of suitable graphite brushes for slip rings at least indicates that they will possess decidedly superior advantages, and it is to be hoped that sooner or later they will be available. There is already at hand confirmatory evidence of their possibilities, in the results being daily obtained on both the iron and bronze rings of turbo fields, synchronous motor fields and slip ring rotors of induction motors. It is true these applications are of a limited nature; nevertheless, the principles involved are identical.

APPLICATION OF SLIP RING BRUSHES

All types of slip ring brushes should be installed so as to cover the full width of the ring, but never so as to permit the brush to overhang the ring. This is easily accomplished by properly "staggering" the brushes, all slip ring brushholders being designed for this adjustment. Metal graphite or "block" brushes are generally installed radially, and with either one or two brushes in each holder. When two brushes occupy the same holder they should be placed side by side—not in "tandem." If in "tandem," the leading brush is packed against the leading face of the holder by the lagging brush, due to the rotation resultant, and the brushes do not wear uniformly. It may be possible to overcome this by changing the brush angle, or by a change in the resultants of spring pressures. As previously stated, the pressure should be from three to five pounds per square inch.

SLIP RING LUBRICATION

For slip rings equipped with copper leaf brushes, vaseline and various light oils are used. The use of these is helpful, but to obtain the best results both rings and brushes must be kept scrupulously free of the brush and ring cuttings. The brushes especially are too frequently allowed to become gummed with copper and other dust. In addition to being kept clean, copper leaf brushes must be trimmed as often as necessary, and the thick bronze plate strips must be kept cut back so as not to come in contact with the rings; otherwise, being of tempered bronze, they will cut the rings rapidly. It has been previously stated that the manufacturers of "block" or metal graphite brushes claim for them the characteristic of perfect self-lubrication; also that in a measure this is true. If, however, the life of rings and brushes is to be regarded as one of moment, there are many instances in which the life of both rings and brushes has been prolonged by the use of light lubricating oils with certain block brushes. Cleanliness and occasional appli-

cations of light oils can do no harm, whereas the omission of both, or either, may result adversely. Almost anything that suggests an improvement in brush conditions is "*worth trying once*."

BRUSHHOLDERS FOR SLIP RINGS

Brushholders for metal graphite brushes have taken forms both foreign and akin to direct-current holders. With these holders the brushes require the usual multiplicity of expensive shunts, the necessity for which, with a proper holder, is at least debatable. Inasmuch as slip ring brushes may be placed indiscriminately around the rings, there is no occasion for maintaining a fixed brush relation to the rings. The ideal holder, therefore, may be in the development of the swivel type, in which the brush may be clamped in the box and the brush itself require no shunt. The box should, however, be heavily shunted to the holder support in order to protect the swivel from possible arcing due to the current passing through the swivel joints. The brush will require occasional readjusting in the holder due to the wear of the brush reaching, from time to time, the travel limit of swivel. (This limit should not permit the holder to come in contact with the ring). This requirement, however, will not approach the work involved in trimming copper leaf brushes, or in cleaning the accumulated dust from between the brushes and holders, as is necessary with present holders.

At the present time a few slip ring motors are being fitted with a holder of the foregoing type, but the value of its general application has not been fully determined. Present holders are designed to take single brushes, or two brushes side by side, or two brushes in "tandem." The last-named holder is the least desirable for the reason previously stated. However, it has the advantage of economizing the space around the ring, and to a degree precluding congestion. Its single objection can be readily overcome by using a partition between the brushes.

BRUSH COSTS

The first cost of a brush is not the final cost. A low first cost may prove an ultimate extravagance. Unfortunately, the final cost, due to the installment method of paying in driblets, is covered up in the bookkeeping, and represents an increase in general maintenance, rather than a clear-cut item covering "brushes." It is decidedly cheaper to pay for and maintain one brushholder and one brush at a fair price than to pay for and maintain two brushholders, two brushes, two shunt attachments, an increased length of brushholder support, an increased length of commutator, a heavier commutator bushing, a longer shaft, a longer bedplate, increased floor space, or even a machine having a greater number of poles. Analyze the "final cost" before being intimidated by the "first cost," and the conviction will follow that the right brush is worth all it costs. Brush costs increase with the exactions imposed upon, but these costs are insignificant when compared to the greatly reduced costs of the machines made possible, to a large extent, by the more expensive but higher grades of brushes. The idea that "a brush is a brush" is a fallacy and should not be encouraged.

Inasmuch as users of brushes must of necessity order brushes, and such orders must frequently pass through many hands before they reach the brushmakers, or the manufacturers of their apparatus, the following suggestions on ordering brushes may be of service:—

ORDERING BRUSHES

Unless the style, type, size and shunt equipment of a brush can be definitely given when brushes are ordered, the following information should be furnished the brushmaker, or the manufacturer of the machine, when an order for brushes is placed:—

1—Size of brush, in the following order:—Length, width, thickness.

2—Bare or copper-coated.

3—Brush angle; also if corners are square or chamfered.

4—State whether rotation is against toe or heel of brush.

5—If to be drilled for shunts, or countersunk, or both, give full particulars.

6—If to be equipped with brush-lifting devices, give full particulars.

7—State whether for one, two or more shunts, giving length of flexibles and style of flexible terminals.

8—Specify if shunts or brush-lifting devices, or both, are to be either attached or supplied.

9—Give all information on the name-plate of the machine.

10—Give diameter of commutator (or rings).

11—State whether or not mica is undercut.

12—Give maximum number of bars touched by the brushes.

13—Give number of segments between center of positive and center of negative brushes.

14—Give number of poles (or brush arms) and number of brushes per arm.

15—State if machine is of commutating-pole or non-commutating-pole type.

16—Give style or type of holder.

17—If brushes in use have not proven satisfactory, state in what respect they have failed.

18—If convenient, forward a used sample of the brushes in service. It frequently happens that a more suitable brush can be prescribed and that an examination of the original brush will not only suggest a substitute having superior characteristics, but at the same time eliminate possible errors in brush dimensions, shunt applications and brush-lifting mountings.

19—Bear in mind that brushholders differ greatly in detail and that the application of shunts for either direct or alternating-current service must be specified; otherwise the shunts might interfere with the pressure springs and a set of brushes be rendered useless.

20—It is also well to furnish a sketch of the brush.

21—If for "try-out" purposes, state what service the machine is doing; hours of service; minimum, average and maximum loads, with duration of each; also if machine is subjected to gas or acid fumes, and what, if any, troubles have been experienced.

From the above it must be concluded that if what is wanted is expected it must be made clear what is wanted. Even then it may not be available. Brush requirements are in no sense stable. It is wise, therefore, to encourage a receptive disposition and to be ready for such advances in the art as may seem worth while.

Poles and Crossarms

THEIR PRESERVATIVE TREATMENT AND OTHER HANDLING BEFORE INSTALLATION

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THIS ARTICLE is intended to give a brief description of the timber-treating situation as it pertains to poles and crossarms; and then to deal with the timber subjects which particularly interest electric operating companies. These subjects are the brush treatment of poles and improved methods of handling and storing poles and crossarms before their installation. Those who are interested in the general subject of wood preservation, both historically and in the details of the various processes, are referred to the 1910 and 1911 reports of the Preservative Committee of the National Electric Light Association. The 1911 report shows why creosote has been selected as the standard preservative for the treatment of line timber: and it gives complete descriptions of the various methods of treatment. The whole matter requires much more description than can be given in a short paper, or, in fact, in any one book on the subject. The main purposes of this article will have been accomplished if it leads to a closer study of the economics of timber problems.

WHEN timber preservation was in its earliest stages a number of preservative fluids were experimented with, among them being solutions of copper sulphate, zinc chloride and mercuric chloride. Creosotes, including coal tar creosote, water gas tar and wood creosote, have been used since the earliest days of preserving work. In the course of progress, combinations were made of creosote with zinc chloride and other chemicals. After a great deal of experimenting, most of the complicated treatments were eliminated and, while the chemical solutions are still used extensively in Europe, they are not employed to any extent in the United States, although there are a few treating plants where so-called emulsion processes combine creosote and zinc chloride in pressure treatments.

Several distinct processes were developed during this period of evolution and, though a number of them still remain, the first in importance and general usefulness is the full-cell, high-pressure system by which creosote is forced into the timber under the pressure of live steam. In carrying out this method the timber to be treated is placed in air-tight treating cylinders. The timber is then steamed, the period of steaming depending upon the condition and size of the timber being treated. When the steam has been withdrawn from the cylinder a vacuum is created and creosote oil is run into the cylinder. Pressure pumps are then started and are continued until the desired amount of preservative has been injected. The full-cell, pressure method is the best treatment for railroad ties and for poles of certain species where the cell structure is such that full penetration can be attained. The full-cell method is costly, and is only justified where an indefinite life is necessary and there is not sufficient mechanical wear to reduce materially the life added by the treatment. For treating timber with the full-cell, pressure method, large cylinders of boiler plate equipped with air-tight doors are used. Gauges are provided to measure the steam pressure, vacuum and the quantity of creosote pumped into the tanks. It can be readily appreciated that very few operating companies can afford to maintain such elaborate outfits. In the southern states, and elsewhere where line timber is subject to rapid decay, it is often found desirable to employ the services of a pressure creosoting company. Some of the electric light, telephone and railroad companies located in the South have adopted this practice and have had sufficient experience to report very favorable results. Only a close analysis of all the economic factors affecting each company's conditions, however, has given the correct answer in these cases; and experience has shown the necessity for careful predetermination of the local requirements.

The next process, in order of importance, is the atmospheric process, which is usually described as the "open-tank" system. This treatment can be carried out very simply, or it can be enlarged to include the features of separate hot and cold treatments. Briefly, the process is to place the timber to be treated in an open tank containing creosote, the creosote having been brought to a temperature of from 180 to 220 degrees F. The timber is kept in the tank for a length of time sufficient to heat it uniformly to the temperature of the preservative. It is then either changed to another tank containing cold preservative, or the hot preservative is drawn out and replaced by a charge of cold preservative at atmospheric temperature; or the timber may be allowed to remain in the tank until the heated oil cools. The theory of this process is that the heat expands the air in the wood cells, and when the cold oil is introduced the sudden contraction creates a vacuum which draws in the oil. The simplest equipment for this type of treatment consists of a tank of suitable dimensions, set high enough above the ground to have a fire beneath it. A derrick or gin pole is provided at the side of the tank for handling the poles. Steam is sometimes used to heat the creosote in the tank, and also, in larger plants, to operate a hoisting engine for handling the poles. Open tank plants may be of simple design, costing only a few hundred dollars, or they may be much more elaborate with complete pumping outfits, storage tanks and special handling facilities. Plants of this kind cost several thousand dollars and require more space and attention. A simpler process than the open-tank method is tank dipping, where the timber to be treated is simply dipped

into a tank containing heated creosote. This treatment gives only a slight penetration and, in many cases, is not as satisfactory as the brush-treating method.*

Brush treating is the simplest of all methods and, while it gives only a superficial treatment, it will yield economical result where the conditions are suited to it. A description of brush treating is given in the following pages.

In order to understand the status of the different treating processes as they are now practiced throughout this country, it is important to become familiar with the various characteristics of the industry. A feature which should be well understood is that the increased life of timber, due to preservative treatment, is practically proportional to the penetration of the creosote and the quantity of creosote absorbed by the treated section of the timber. In making this statement it is assumed that the quality of creosote is constant. Some species of timber are more penetrable than others and the rate of absorption varies; also, a given species may not have a constant rate of absorption because of varying degrees of dryness, differences in cell structure owing to dissimilar conditions of growth, and differences due to variables introduced by the treating process. It is probably because of these variables and the lack of a uniform standard of measurement that complete and authentic records have not been compiled, and that little can be learned regarding the specific results with any one process.

BRUSH TREATMENTS

When the reports of the Preservative Committee of the National Electric Light Association were issued, sufficient evidence had not been collected to show conclusively that brush treatment of poles would produce really economical results. Those reports were necessarily conservative, and the committee could only be specific in recommending pressure treatments for pine poles and heavy open-tank treatments for poles of such species as chestnut and cedar. Those recommendations still stand and are applicable to companies operating under pertinent conditions.

The studies of the past three or four years have developed the following points:—Properly applied brush treatments offer to many operating companies a simple and effective method for chestnut and cedar poles. In some parts of the South, and other sections where the climate causes speedy decay of timber, pine poles require pressure treating; and even the more durable species, such as chestnut and cedar, should have a heavy open-tank treatment. The advantages enjoyed by companies located in many of the northern, middle and western states are that brush treating avoids the heavy investment, the more complicated operations, and the additional space and isolation required by open-tank plants. If proper brush treating will add from two to five years to the life of a pole, any estimated costs based on that method are apt to be closer to the actual costs than those of the more elaborate processes. This uncertainty of realizing a longer pole life, through heavier treatments, is due to the frequent conversion of overhead plant to subway plant, compulsory pole replacements and other unanticipated causes. Premature pole renewals have been increasing of late years, principally because of the more substantial construction required by heavier loading, changes due to civic improvements, and a very general increase in the exactions which are so frequently imposed upon utility companies.

Even with due regard for the diminishing supply of poles, and with full recognition of the fact that deferred replacements reduce maintenance charges, it may often be wise to adopt the preservative practice which affords the greatest flexibility of plant and which offers the least resistance to these unavoidable changes. To illustrate what is meant by plant flexibility, as afforded by the brush-treating process, attention is called to other ways of extending replacements. It has been demonstrated that many poles can be mechanically reinforced at the butt so as to attain a total life more nearly equal to the life of the upper part of the pole, which part would often have a very long life, the limit being reached, not because of material decay in the upper section of the pole, but because of deterioration brought about by mechanical wear and weathering. Mechanical reinforcement of poles cannot be applied in all localities, but the sections where objections to it are raised are often those which are the first to be converted to subway or which have an abnormal number of premature pole renewals due to a higher standard of locality requirements.

To make the description of the proper method of applying brush treatments concise, the field instructions recently issued by one operating company may be taken as representative of the best practice. These instructions are, in part, as follows:—

SEASONING AND CARE OF POLE YARDS

Only seasoned poles are to be treated, and even the seasoned poles must be dry when they are treated. For this reason, care should be taken not to store poles directly on the ground where they can become soaked from lying in snow or water. Dry and comparatively warm spells should be selected for treating. If poles are neatly piled, raised on racks from the ground, and are slightly separated, seasoning will not only be accelerated, but the poles will be much more conveniently handled while being treated and in subsequent operations. All pole yards are to be maintained in a clean and orderly condition, and they are also to be kept free of weeds, as weeds infect timber and are a nuisance to the workmen.

PREPARATION OF BUTT FOR TREATMENT

The part of a pole most subject to decay is at the ground line, and immediately above and below it. For this reason, the entire butt of a pole need not be treated, as the creosoting at the end of the butt is unnecessary. In order to properly prepare a pole for treatment this

*Drawings and construction details of several types of pole and crossarm treating tanks are given in the 1911 report of the Preservative Committee of the National Electric Light Association.

part of its butt must be shaved clean of all bark, and bad spots of soft and rotten timber should be shaved away until only sound timber is left for the creosote. Inexperienced workmen are apt to remove only the outer or heavy bark, leaving the inner bark, which is impenetrable by the creosote.

SECTION OF BUTT TO BE TREATED

The length of the treated surface should be not less than three or four feet, and may be enlarged proportionately for the longer poles. The ring is to be painted so that, when the pole is installed, one foot of the treated section will be above the ground line.

PRESERVATIVE

The preservative must be a creosote oil conforming to the specifications for brush-treating oil, as recommended by the National Electric Light Association's Timber Preservative Committee report of 1911.

TOOLS AND OTHER EQUIPMENT

The tools and other equipment are as follows:—

Brush—A three-knot, wire-bound roof brush, to be ordered without handle. The handle should be cut to desired length and may be made of a broom handle or other suitable stick. This brush is for applying the hot creosote to the poles.

Pail—A fourteen-quart, galvanized-iron pail is best for this work. Such pails can be used for heating on small jobs, and to contain the hot creosote when brushing the poles. Where a heating tank is used the oil can be ladled from the tank into a pail, and the temperature of the oil in the pail can be kept up by using a kerosene, charcoal or other small furnace.

Furnace—This must be a portable kerosene furnace of safe and efficient type, or a charcoal pot stove of suitable size. The kerosene furnace is preferable for quickly heating, and the charcoal pot stove for continuously heating a small quantity of oil.

Thermometer—This is a special type of field thermometer for taking temperatures of the creosote oil. It is a mercury thermometer, mounted in a wooden frame which has a handle at top and a metal cup at the mercury end. This cup holds a small quantity of the oil when reading is taken. The scale reads up to 230 degrees F. The wooden frame can be notched at the low and high limits so that the workmen can more easily observe readings.

Heating Tank—The kind of heating tank to be used depends upon the quantity of poles to be creosoted and the local yard conditions. A plain steel barrel can be set up on a temporary fireplace, in which can be used coke, charcoal, coal or wood. There is also the tar oven type tank, which has a self-contained fireplace in the bottom. Either of these tanks will answer all ordinary requirements, but special designs for unusual conditions can be procured.

METHOD OF APPLICATION

The preservative should be thoroughly mixed by stirring, or other suitable means, while in its original container. When the mixing is completed the preservative should be poured into the tank or pail, as the case may be, and then heated to a temperature of not less than 150 degrees F., nor more than 200 degrees F. The preservative should be held between these temperatures while work is going on. The thermometer should be used to check the temperature of the preservative.

The hot preservative should be taken up on the brush and applied to the pole surface. Special care should be taken to paint all gains, pole tops, and to fill knot holes, seasoning checks, cracks and other openings in the pole surface. The pole should be turned during the treatment so as to keep uppermost the surface to which the preservative is being applied. The preservative should be worked well into the wood by careful brushing and a sufficient quantity should be left on the surface to give a wet appearance after the application is finished. As the effectiveness of treatment depends upon the penetration by the preservative, care should be taken at each application to see that all parts of the exterior of the pole, within the section to be treated, are reached by the brush.

Two coats of preservative should be applied to each pole treated. At least one day should be allowed between the application of the first and second coats. The second coat should be applied at least two days before a pole is set.

PRECAUTIONS TO BE OBSERVED IN APPLYING THE TREATMENT

As a precaution against fire, a pail of sand should be kept near each heating vessel. If the preservative should catch fire, the flames can be smothered by applying a cover to the heating vessel or by using the sand. Any method of extinguishing the fire, which might spread or scatter the burning compound, should be avoided. As the fumes arising from preservatives have a tendency to affect the skin, it is desirable to keep to the windward side of the heating vessel, and long-handled brushes should be used. Lard or vaseline, when desired, can be used to protect the faces and hands of the workmen from the effect of the fumes. Care should be taken to avoid spattering the hot compound, as injury may result if drops reach the flesh of the workmen.

The temperature of the oil should be checked frequently, as creosote will boil over at 212 degrees F. (the boiling point of water); and care should be taken not to fill the heating vessel with creosote. Observance of these features will prevent fires and accidents to workmen. The use of linseed oil and sawdust, applied separately, will be found a satisfactory means of removing creosote from the hands.

HANDLING OF TREATED POLES

The protection of brush-treated poles from decay is dependent upon a relatively thin exterior layer which has been penetrated by the preservative; therefore, care should be taken to avoid injury to the treated section through the dragging of poles, or by the tools used in handling poles.

The oil in storage should be properly protected from excessive variations in temperatures and from admittance of any foreign matter. The tools, tanks and other equipment should be properly maintained, and their cost, efficiency and other details should be made part of a complete historical record. A proper record

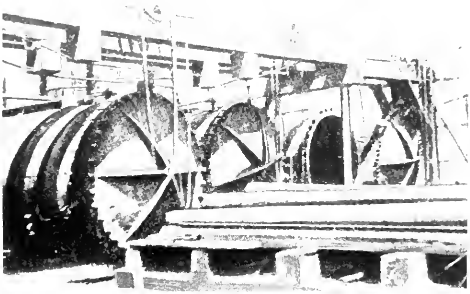

FIG. 1—TANKS FOR FULL-CELL, HIGH-PRESSURE SYSTEM OF TREATING POLES

of the treatment of each pole should be maintained. The standard pole record can be made to include this record. If a pole is set green, and, therefore, is not treated, such information should be noted on its card. If the butt of the pole has been treated, date of treatment should be noted on its card.

Fig. 2 shows the location of the creosoted ring, and indicates the gains and other parts of the pole which should be treated. A simple brush-treating outfit, consisting of brush, pail, thermometer and furnace, is shown in Fig. 3. Fig. 4 shows how the workman applies the brush treatment, and also illustrates the convenience gained by keeping the poles on suitable racks. Fig. 5 shows the decay of a pole at the ground line. This is a typical case and explains why treatment does the most good when applied to that section of the pole. If the butt of this pole were excavated the decay would be found extending downward only from one to three feet.

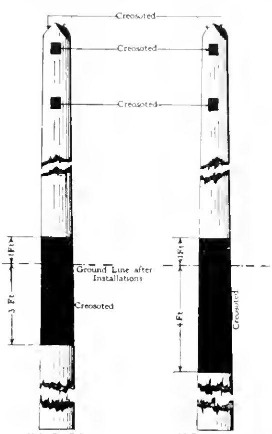

FIG. 2—LOCATION OF THE POLE PARTS WHICH ARE CREOSOTED BY THE BRUSH TREATMENT

TREATMENT OF CROSSARMS

Investigations to date have not thrown sufficient light on the results of creosoting crossarms to justify final conclusions. The lack of authentic data of this kind is unfortunate, and it will undoubtedly take a number of years to collect information that will prove whether such practice is justified. Some companies have creosoted their crossarms, but only a few seem prepared to recommend it or to offer convincing records. Others are not certain of any beneficial results, while the majority seem to lack positive opinions. A heavy

FIG. 3—BRUSH-TREATING EQUIPMENT

Consists of 14 quart galavanized pail; thermometer; three-knot, long-handled brush; kerosene furnace (charcoal pot to be used for continuous heating).

treatment of the proper kind of creosote would undoubtedly preserve a crossarm; but there are disadvantages in the use of creosote, as it has been known to weaken timber, under certain conditions of treatment; and the oozing of the oil from the arms in hot weather is a decided nuisance. There have been claims that the oil increases the inflammability of the wood, but this, too, is a matter which has been disturbed by conflicting reports. One feature is certain:—A crossarm, being a much smaller piece of timber than a pole, can be thor-

FIG. 4—BRUSH-TREATING PROCESS

Workman can stand on the pole or at its side.

oughly seasoned and it does not experience conditions of accelerated decay such as affect the butt section of a pole. Crossarms derive a considerable extension of life through proper painting and, in many cases, proper

painting will carry a crossarm to the life of its pole. Where this coincidence of life limit can be made to exist, and where heavy creosoting would preserve an arm beyond its mechanical life, it is a justifiable assumption that painting is the more desirable practice.

FIG. 5—TYPICAL POLE DECAY AT THE GROUND LINE

The same company's field instructions covering the handling and painting of crossarms are, in part, as follows:—

All crossarms are to be thoroughly seasoned before being painted. Crossarms should not be stored in damp places nor where there is poor circulation of air; and, when unpainted, should not be exposed to the weather for more than three months. They should be stored and racked in accordance with the directions given for such work. Illustrations furnished with these instructions show the proper method of piling crossarms for storage and seasoning purposes. The roofing should be provided if the crossarms are stored out of doors under unfavorable weather conditions. Crossarms may be seasoned indoors and kept stored there if the air is dry and has reasonable circulation. These methods will facilitate drying of the arms and will most quickly put them in proper condition for painting.

When crossarms have become seasoned they should be painted as follows:—First, one coat of white lead, applied with a brush. Second, after a period of twenty-four hours, one coat of standard pole paint, applied with a brush. Crossarms are not to be dipped into the paint. The white lead should be mixed sufficiently thin to make it work well into the wood, and both the lead and the pole paint should be applied evenly and firmly in order that crevices and exposed parts of the arm will be thoroughly painted.

Instructions should be issued to the men who do the painting to work the paint into all seasoning checks and other openings in the wood; also to inspect each arm carefully to see that it has no serious defects and that decay has not already set in. This is important, and advantage should be taken of such opportunity to weed out defective arms.

Fig. 6 shows a method of storage which will ensure rapid but thorough seasoning of crossarms. The roof

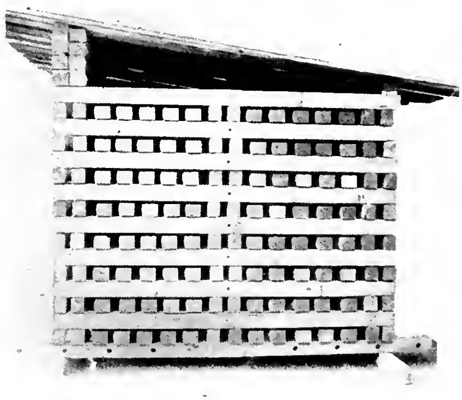

FIG. 6—VIEW OF PROPERLY RACKED PILE OF UNPAINTED CROSSARMS

With roofing to protect them from unfavorable outdoor weather. This illustrates the proper method of racking arms for either indoor or outdoor seasoning. Crossarms stacked all in the same direction without ventilating spaces will not season properly; they may warp and are apt to become mildewed, a condition which starts decay.

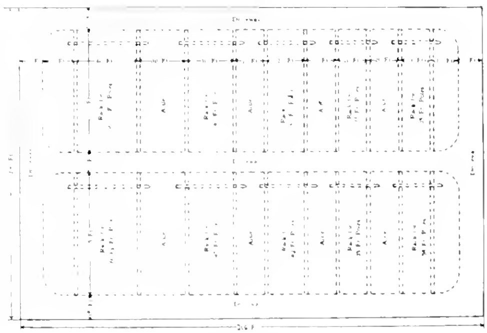

FIG. 7—DIAGRAMMATIC LAYOUT OF A MODEL POLE YARD

Approximately 1000 poles capacity. In practice the yard might have a different arrangement of racks, owing to the greater or less use of some of the sizes of poles. Such a layout, however, shows a general arrangement of racks and driveways that would give the best working facilities. This would also economize space, without cramping, so that poles will not have to be piled in high heaps on the racks. The poles may be loaded onto the rack from a driveway at either end, and may be taken from the rack in the most convenient manner. The principal advantage of such racking is that the poles can be separated for seasoning and for the usual operations of shaving, trimming, gaining, roofing, painting and creosoting. Where railroad siding can be brought to yard, the arrangements should be such that the poles can be skidded from the cars to the incoming end of the seasoning racks. The racks may be built from 12 to 36 inches above ground. They may be made to any slope at any desired point, so that the grade will aid in transferring poles from the loading end to working end of the rack.

can, of course, be omitted in case the crossarms are not exposed to the weather.

STORAGE OF POLES

The foregoing refers particularly to the brush treatment of poles and the storage and painting of crossarms. It now remains to illustrate the decided advantages of racking and storing poles properly. Fig. 7 shows an improved pole rack, the construction of which is illustrated in Fig. 8. Figs. 9 and 10 show actual working operations and illustrate the convenience and safer conditions of a properly built pole rack.

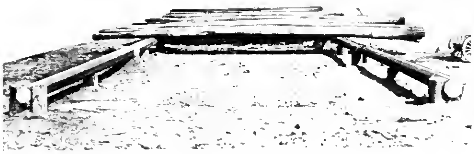
FIG. 8—GENERAL CONSTRUCTION OF POLE RACKS

If pole racks are built, incoming poles can be stored on portions of them and there kept until they are sufficiently dry to permit the application of creosote. When the poles have reached this stage they can be easily rolled along the racks to a convenient place for the shaving, trimming and gaining work. After shaving, trimming and gaining they can be rolled to a convenient place for the butt treatment and painting of the upper part of the pole. The cost of these racks should be slight, as old, sound poles or old rails and metal beams can be used; and the work can be done by the pole gangs at odd times. Where yards are owned, or are apt to be leased indefinitely, the uprights should be brush-treated with two coats of creosote. The installation of these racks will provide many advantages over cruder methods; and such practice ought to be followed even if creosoting of the poles is not adopted. The principal advantages are:—


FIG. 9—VIEW OF POLE YARD
Illustrating the convenience of pole racks in performing the various operations on poles.

Increased safety, as accidents may occur where poles are piled carelessly in high heaps.

The greatly improved appearance of pole yards.

Proper sanitation of yards to prevent the propagation of timber-destroying fungi.

Convenient and efficient conditions for seasoning, shaving, trimming, gaining, roofing, creosoting and painting poles.

Convenient and efficient conditions for separating, classifying and recording different sizes of poles.

Convenient and practical layout of driveways, giving proper conditions for handling and loading operations.

COSTS

In conclusion, it should be stated that data giving the specific cost of any particular treatment or the relative costs of the several kinds of treatment are purposely omitted. It is felt that the extreme variation of costs throughout the country might cause such comparisons to be misleading, and any general figures would not be useful for local application. The cost of equipment varies considerably, and the cost of labor and creosote would not be constant. Also, there is always a material difference between the costs of small and large operations; and whether the work is done at convenient or inconvenient times. Those companies which are contemplating treating work should secure prices of creosote and carefully estimate the cost of the equipment which would be needed in carrying out the process best suited to the local conditions. The local data should then be checked with the estimates and other information given in the National Electric Light Association preservative reports and in the bulletins which have been issued by the Forestry Service bearing upon its creosoting investigations. It is also suggested that inquiry be made regarding other member companies' experiences. Probably the Question Box of the *National Electric Light Association Bulletin* would be a good channel for obtaining such information. It is desirable for all companies to co-operate in a movement to open up this subject and to stimulate fuller discussion of preservative problems.


FIG. 10—METHOD OF LOADING OR UNLOADING POLES ON RACKS


FIG. 11—POLE RACK BUILT OF OLD STEEL RAILS ON CONCRETE PILLARS

The Application of Current-Limiting Reactors

H. H. Rudd and W. M. Dann

CURRENT-LIMITING reactors are designed to limit to a predetermined value the current that can flow when a short-circuit occurs in alternating-current circuits in which they are placed. Limiting the short-circuit current benefits both the generating and distributing system by reducing the mechanical stresses in connected apparatus, and by minimizing the reduction in voltage due to a short-circuit.

PROTECTION TO APPARATUS

The current at short-circuit depends upon the impedance of the circuit. The mechanical stresses that are produced at such a time in the windings of connected apparatus and in switches and cables are proportional to the square of the current. If the impedance of the circuit is low, and hence the short-circuit current high, these mechanical stresses may become tremendous, and unless everything in the circuit is substantially constructed and all windings are securely braced, distortion and breakdown may result. By introducing an additional reactance in the circuit, the impedance is increased and the short-circuit current is reduced. If by inserting reactance in the circuit the total amount of reactance is doubled, the short-circuit current will be halved and the stresses reduced to one-fourth of their previous value.

PROTECTION TO SERVICE

The heavy currents that can flow in a system which is unprotected by reactance coils, besides creating severe mechanical shocks which may cause an interruption of the service, produce a large drop in voltage, due both to the impedance drop in the circuit, and to a demagnetizing effect produced by the heavy current on the generator fields. This drop in voltage affects the whole system. Reactors may be placed in the circuits in such a way that they will not only reduce the mechanical strains due to short-circuit, but will also practically localize its effects in the feeder or section where it occurs, and its effect on other feeders or bus-sections will be minimized.

RATING OF REACTORS

It is convenient to express reactance as a percentage of the normal voltage rather than in terms of the voltage drop for a certain current. A single-phase system is shown in Fig. 2. The line current produces a drop of 115 volts through the reactance. The percentage reactance, therefore, is 115 divided by 2300, or five percent. The relations for a three-phase system are shown in Fig. 3, where an 11 000 volt system is taken for example. As the voltage across phases is 11 000 volts, the voltage between line and neutral is 6350 volts. The current is in phase with the voltage from line to neutral, and therefore when this current produces a drop through the reactance coil it is expressed as a percentage of the voltage in phase with the current (317.5 ÷ 6350), or five percent. In this case the k.v.a. rating of each of the reactors will be, if they are single-phase, 317.5 times 100, or 31.75 k.v.a.; or, if a three-phase coil is used, three times 31.75, or 95.25 k.v.a.

The characteristics of a current limiting reactor are definitely fixed by a statement of

a—The reactance expressed as a percentage of the normal voltage of the circuit.

b—The characteristics of the circuit in which it is to be placed, with respect to (1) normal k.v.a., (2) normal voltage between wires, (3) phase of the circuit, (4) frequency.

c—The temperature at which it operates under maximum continuous current.

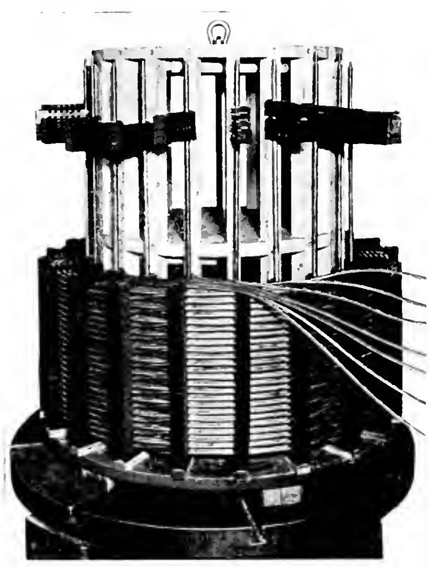

FIG. 1—A REACTANCE COIL PARTLY WOUND
Showing method of transposition of multiple conductors.

The normal current for the coil will be the normal value of the current of the circuit in which it is placed. For a single or two-phase circuit this current will equal the normal k.v.a. per phase divided by the normal line voltage; for a three-phase circuit it will equal the total normal three-phase k.v.a. divded by 1.73 times the voltage between wires.

The normal voltage drop across the coil will be developed when normal current at normal frequency is flowing through the coil. This voltage drop will be the

given percentage of the normal voltage between wires in a single-phase or two-phase circuit; or the given percentage of the voltage from line to neutral (= voltage between wires ÷ 1.73) in a three-phase circuit.

Current-limiting reactors must of necessity carry the maximum overload currents which the circuit is called

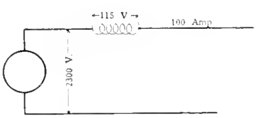

FIG. 2

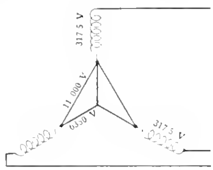

FIG. 3

Fig. 2—Reactor in a single-phase system.
Fig. 3—Reactors in a three-phase system.

upon to carry, and with a reasonable ultimate temperature. Reactors of this kind, however, can safely operate at a higher temperature than would be safe for generators and transformers, due to the open and well-ventilated construction which is possible, and for the reason that materials which will not be injured by such temperatures can be used. Since a higher operating temperature is reasonable and is an important factor in reducing the size and cost of such coils, a temperature rise of 75 degrees C. under maximum continuous current represents common practice.

Coils should be rated for their maximum continuous current condition because, owing to their open construction, a coil will reach its maximum temperature for a given load within a period of a few minutes. Specifying that the coils of the cables should stand an overload for two hours or for one hour without exceeding a definite rise is practically equivalent to requiring that the coils shall stand that load continuously.

LOCATION OF REACTORS

Current-limiting reactors may be used to advantage in the generator leads; between sections of the bus; in

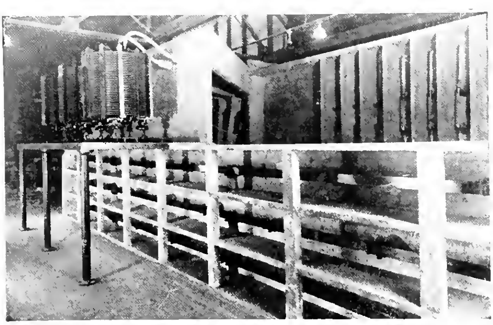

FIG. 4—BUS STRUCTURE OF BRUNOTS ISLAND POWER STATION OF THE DUQUESNE LIGHT COMPANY, PITTSBURGH
Showing bus-tie reactance coils.

the outgoing feeders. Past experiences with short-circuits will usually serve to show where such troubles are most likely to occur; having data of this kind, a study of the system will determine the most suitable location of the reactors.

If the generator windings show any signs of weakness and the records show that short-circuits between the generators and the bus-bars are not uncommon, reactors should be placed directly in the generator leads. This is the surest method of protecting a weak generator or its circuit-breakers; it is not very effective, however, in limiting the current that can flow into a short-circuit on some feeder, and it does very little good in minimizing the drop of voltage at the bus-bars and preventing generators from falling out of step.

If a number of generators are used in parallel, a short-circuit in any generator or between a generator and the bus-bars will cause all of the generators to feed into the short-circuit, and the bus-bar voltage will drop practically to zero. If such short-circuits are likely to occur, it is desirable to sectionalize the bus and place reactors between the sections. This will limit the current that can flow between generators, and will have a

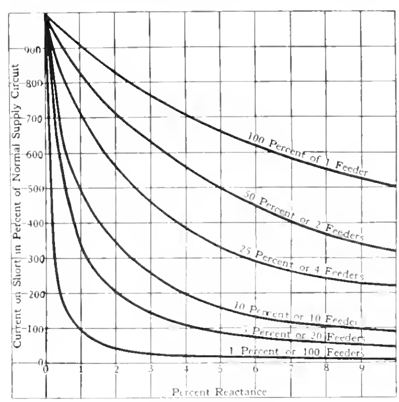

FIG. 5—EFFECT OF VARIOUS FEEDER REACTANCES IN LIMITING THE SHORT-CIRCUIT CURRENT IN FEEDERS
Generator reactance assumed to be 10 percent.

marked effect on maintaining the voltage of the bus-bars when a short-circuit occurs.

If a large percentage of the short-circuits occur outside of the station on the feeders (and statistics show that this is where the majority of such troubles do occur), reactors placed in the feeder circuits will be very effective in protecting the apparatus and maintaining service. The feeder reactor will practically localize the trouble in the circuit where it originates; the reduced short-circuit current in that one feeder will be of little importance in its effect on the generators and therefore on the bus-bar voltage; the feeder circuit breakers will be protected and the circuit opened more safely.

It has been the common experience in cases where the generating capacity of a station is increased from time to time that the feeder cables and circuit-breakers begin to give trouble on account of the increased severity of short-circuit troubles. When reactors are inserted in the feeder circuits, additions to the generating capacity

become of very much less importance in increasing the short-circuit troubles. In stations of the usual type where the feeders are relatively small in capacity compared to the total generating capacity, feeder reactors of the proper size will render the feeders practically immune from further troubles, no matter how large the generating capacity becomes.

In the past, with an addition of a considerable amount of generating equipment to a system, it has often been necessary to change the oil circuit-breakers, owing to the fact that they would not be capable of opening a short-circuit with the additional amount of power behind it. Assume, for instance, a 10 000 k.v.a. power station having ten 1000 k.v.a. feeders. Further assume that the switch is capable of rupturing a short-circuit of 200 000 k.v.a. If the generators have ten percent reactance a short-circuit in the feeders would be equivalent to a 100 000 k.v.a. short-circuit to be handled by the switch, which would have ample capacity to take care of this condition. However, if the capacity of the station be doubled, it will be seen that the short-circuit to be handled by the switch is 200 000 k.v.a., or is up to the limit of the rupturing capacity of the switch. Assume, now, that a reasonable amount of reactance is to be inserted in each feeder, say three percent. Under condition of short-circuit with unlimited power behind the switch, the maximum k.v.a. rupturing capacity that the switch will have to take care of will be 33 000. In other words, introduction of a reasonable amount of reactance in series with the feeders makes the oil circuit-breakers suitable to take care of operating conditions, no matter what the size of the station may become.

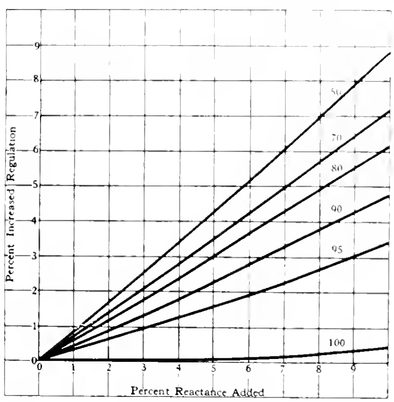

FIG. 6—INCREASE IN REGULATION FOR CIRCUITS OF VARIOUS POWER-FACTORS WHEN REACTANCE IS ADDED

When a short-circuit occurs on a system the voltage will drop, depending on the magnitude of the short-circuit and the inherent characteristics of the generators. Reactors introduced will limit the value of the short-circuit. A heavy severe short-circuit, such as may occur when there are no reactors, will cause the voltage to drop to a low value in a few cycles, whereas on a less severe short-circuit, the time taken for the voltage to drop to the same low voltage will be longer.

Synchronous apparatus will stand a complete loss of voltage for a few cycles only, but will stand a reduction in voltage for a longer period. It is important then that the value of the short-circuit be small, and that it be cleared in the shortest possible time. Introducing reactors will limit the maximum value of the current, and with the latest type of relays, the time required for selective action can be reduced and the time setting of the feeder circuit-breakers can be made shorter. In other words, the trouble can be localized and cleared before the apparatus on the rest of the system is affected.

In considering the amount of current that will feed into a short-circuit, the synchronous apparatus connected to the system in the form of load must be taken into account, as on a short-circuit there is a tendency for them to feed back into the system, due to the inertia of their rotating elements.

One of the serious effects of a drop in bus-bar voltage is that all synchronous apparatus connected to the system will be likely to fall out of step. Reactors placed directly in the generator leads will offer no protection against such trouble. Bus-bar reactors will be effective in confining the trouble to one section of the bus. Feeder reactors will be most effective, as they will minimize the effects of a short-circuit on the bus-bar voltage.

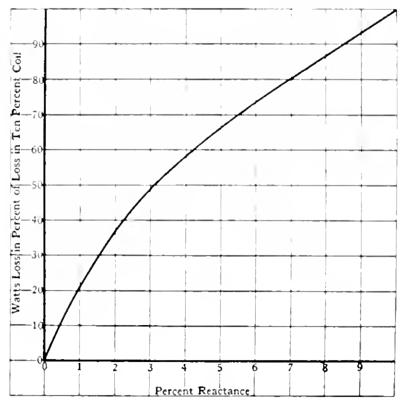

FIG. 7—WATTS LOSS IN REACTORS OF DIFFERENT SIZES

The size and number of generators in a system where the need for reactors is felt, the size and number of the feeders, the cost of the reactors and the space available for their installation are some of the factors to be taken into account. The study of a particular system might result in a combination of more than one of the locations referred to, or perhaps all three. For instance, the bus-tie reactance coils shown in Fig. 4 are connected between the sections of the bus-bars, but are normally short-circuited by quick-acting automatic oil circuit-breakers, which open on heavy overload and cut the reactors into the circuit.

AMOUNT OF REACTANCE

Reactance may be compared to life insurance. The amount should be sufficient to give protection; it should not, however, be so great that it is a hardship to carry it. With no reactance, no protection is given. With an unreasonably large amount of reactance the first cost

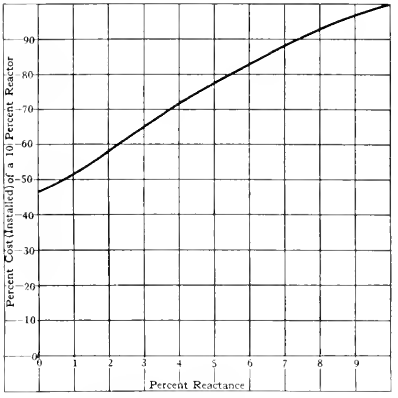

FIG. 8—RELATIVE COSTS OF REACTORS OF DIFFERENT SIZES

and the cost of the electrical losses in the reactors form an excessive premium to pay.

In considering the amount of reactance to be placed in the leads of generators, the armature reactance of the machine and the short-circuit current it would allow, if left to itself, must be considered. A high-speed turbogenerator may have from 7.5 to 10 percent inherent reactance at the instant of short-circuit; a slow-speed engine or waterwheel type of generator may have twice this amount. Five percent reactance added externally to the turbogenerator with its 7.5 percent reactance will reduce the current at short-circuit to 60 percent of what it would be without protection, and the mechanical stresses would be reduced to 36 percent. The same amount of reactance added to the slow-speed generator with its 15 percent inherent reactance will reduce the short-circuit current to 75 percent of what it would be without external reactance, and the mechanical stresses would be reduced to 56 percent. The inherent characteristics of the generator, then, play an important part in fixing the right amount of external reactance to get a certain amount of protection for a generator.

The amount of reactance which should be placed between sections of a bus-bar can usually be determined only by a careful study of the layout of the system. In general, a compromise must be effected between a large amount of reactance, which would have the maximum effect in protecting the system and maintaining bus-bar voltage, and a small amount of reactance, which would permit more nearly equal loading of the generators in parallel, under normal conditions.

The amount of reactance to be placed in feeders will depend upon the size of the feeder, the relation its capacity bears to the generator capacity, and the capacity of the circuit-breakers. Consider a station having a generating capacity of 10 000 k.v.a., the generators having an inherent reactance of ten percent. If the output is distributed over ten 1000 k.v.a. feeders unprotected by reactances, a short-circuit on any feeder will draw 100 000 k.v.a. from the generators; this is one hundred times the normal capacity of the feeders. The reactance of the generators is therefore equivalent to one percent reactance in the feeders. If three percent extra reactance is placed in each feeder, the conditions will be equivalent to a total of four percent; the short-circuit current will then be limited to twenty-five times the normal current of the feeder, or 25 000 k.v.a. on the generators, and the mechanical stresses in the system will be reduced to only 6.25 percent of the value they would attain without the three percent reactances.

If the 10 000 k.v.a. generator capacity is distributed in two 5000 k.v.a. feeders unprotected by reactors, the short-circuit output of 100 000 k.v.a. represents twenty times the normal capacity of the feeder, and the generator reactance is equivalent to five percent protecting reactance in the feeder. This current is less in proportion to the normal current than in the case of the 1000 k.v.a. feeders with their three percent reactances. As far as protection to the feeder itself is concerned very little extra reactance, if any, is required. To limit the generator current to the same figure as in the previous case, and thereby keep the bus-bar voltage up to the same degree, would require an extra feeder reactance of fifteen percent. To get the equivalent protection for the bus-bar voltage, the percentage reactance for each feeder may therefore be reduced as the number of feeders is increased.

EFFECT ON REGULATION

Increasing the reactance in the system results in a slightly lower power-factor and slightly poorer regulation, the effect on the regulation being more marked if the operating power-factor is much below unity. However, the amount by which the voltage of the system is lowered is not seriously large and can be compensated

FIG. 9—WESTINGHOUSE FEEDER REACTANCE COILS, BRUNOTS ISLAND POWER STATION

for by increasing the voltage of the generators. The amount by which the voltage of the system is lowered by the addition of reactance for several different power-factor conditions is shown in Fig. 6. For example, if five percent reactances are added in all of the feeders of a station and the operating power factor is 80 percent, the generators should be excited to give three percent more voltage, to maintain the same bus-bar voltage that would be secured without the reactors.

EFFECT ON LOSSES OF SYSTEM

The losses of reactors expressed in watts, which are due to the losses in the conductors, form an appreciable amount and should be taken into consideration in laying out the reactors for any system. These losses will depend to a very considerable extent on the particular characteristics of the coils involved. They will, however, be approximately 0.2 to 0.5 percent of the total kilowatts of the circuit on which they are to be used. Fig. 7 shows the way in which the losses vary with different sizes of reactors. If for a given feeder a ten percent coil has a loss of 100 percent, a five percent coil would have a loss of approximately 66 percent and a 2.5 percent coil of 43 percent.

COST

The costs of current-limiting reactor units of different sizes are not directly proportional to their capacity; they follow more nearly the cost characteristics of a line of transformers or generators; i. e., the larger the size the less is the cost per unit of reactance. In Fig. 8 the cost of a ten percent reactor is assumed as one hundred percent, and shows approximately what the cost of less reactance would be in terms of the cost of the ten percent unit.

The total expense of providing reactance is not alone in the cost of the reactors themselves; the cost of providing space and actually installing them is involved as well. Taking this into account it will be found that three percent coils, for instance, can be provided with but little additional expense over one percent or two percent coils.

ADDITIONAL ADVANTAGES OF REACTANCE COILS

A system consisting of two or more generating stations in parallel will be more stable if reactance coils are used. The stability of the system depends upon the synchronizing power tending to hold the generators in step. A sudden load or disturbance near one station may cause its generators to drop in speed. This will cause a shifting in the phase of their voltage. The difference in this voltage and the voltage of the other generators will be relatively small and will be almost 90 degrees out of phase with the generator voltages. This out of phase voltage will circulate a local current between the generators and, if the circuit has plenty of reactance, the phase of this local current is displaced almost 90 degrees from the relatively small voltage which causes it, or in other words, is almost in phase with the generator voltage, thereby giving the maximum synchronizing power.

Electricity in Woodworking

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SINCE TIMBER in its many finished forms bears a very close relation to our everyday life, it is natural to suppose that many people are interested in the improvement of the woodworking industry. Statistics show that there are more wage-earners, a larger number of plants and a greater horse-power of equipment represented in the manufacture of wood products than under any other classification. The following article outlines a few of the many advantages which have accrued to the woodworker through the use of electricity, and indicates some of the problems encountered by the commercial electrical engineer.

THE one use of electricity which is practically universal with all plants is that for lighting. It is by far the most satisfactory and safest light source available. A considerable portion of work, especially in finishing mills, is done under artificial light, and too often lighting of the plant has not been given its proper attention. It must be remembered that where the plant does not have good natural lighting the proper arrangement of modern incandescent lighting units will materially assist production and lower the accident risk.

A general discussion of the advisability of using electric power for driving the various machines in the factory must necessarily cover two conditions,—first, that of the new plant just being installed, and second, the old plant at present driven by some other motive power. A great many of the points considered in the first case will apply to the old plant being changed over.

In locating the sawmill where the incoming material is received direct from the forest it is necessary to consider the location of the supply of raw material, and to place the plant so that the incoming logs may be handled economically. For the finishing mill the features affecting location are quite different. A group of factories are frequently located in some particular section of the country, turning out a certain product with apparently little reason for such location. Here it is often the case that formerly the raw material could be obtained easily at this point and local conditions appeared ideal to some-

one wishing to engage in this particular industry. Workmen proficient in this class of industry were attracted, and when the first company branched out, or when another company, wishing to engage in the manufacture of a similar line, found labor and other conditions satisfactory, they located in the same section. Recently a

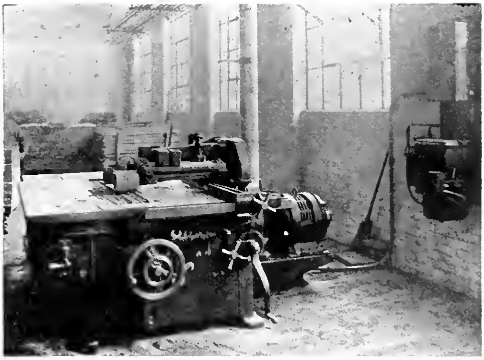

FIG. 1—A COMPACT METHOD OF APPLYING MOTOR DRIVE AND MOUNTING CONTROL

This is a 10 hp, 1740 r.p.m. squirrel-cage, motor direct connected to self-feed edging and ripping saw; maximum capacity five-foot stock.

large number of factories have found it to their advantage to select a location more particularly with reference to the disposal of the finished output. In the latter case it is often desirable to do away with all unnecessary smoke and objectionable gases, such as would result from a steam or gas plant, and to take advantage of electric drive where current for operation may be obtained from a local power company. Also, in all types of factories, the better class of labor will be attracted to those plants where working conditions are the best and where risk of accident is reduced to a minimum. It is not to be denied that a great advance in these respects

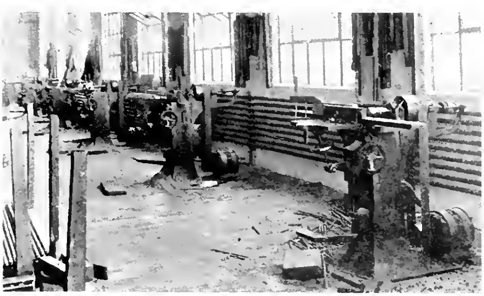

FIG. 2—A ROW OF HORIZONTAL, SINGLE SPINDLE BORERS

Each driven by a two hp, 1720 r.p.m. squirrel-cage motor. The motor is started with a knife switch, which is mounted on opposite side of borer in an enclosed metal box.

has been brought about by the advent of electric motor drive. In the construction of a new plant experience has also shown that individual motor drive throughout will allow the use of a building of much lighter construction than would be required to support the heavy shafting and withstand the strains entailed by any other form of drive.

If motor drive is decided upon at the time of constructing a new plant the question will arise as to whether power for operating the motors will be generated in a power house installed in connection with the plant, or whether this extra expense will be eliminated and a contract for the supply of power entered into with the local central station. Where power is purchased the fire and accident risk incident to the proximity of high-pressure boilers is entirely eliminated. If steam is required for dry kilns, or heating, this may be generated in a low-pressure boiler taken care of by unskilled labor. Where power is generated a very considerable amount of supervision is required from

FIG. 3—A CONVENIENT METHOD OF MOUNTING A MOTOR ON THE HEAD OF A SWING CUT-OFF SAW

those in authority, which must be taken into account as an appreciable item. It is very often necessary to operate small sections of the shop outside of regular hours to take care of rush orders, and where power is purchased this work can be handled with a cost for power only in proportion to the actual amount of power used. In all live organizations there will come a time when it will be necessary to increase the production of the factory by installing additional equipment. With a plant driven from a single power unit, such as a steam or gas engine, it is too often the case that new additions are provided for by extending the shafting or by belting from the present shafting until the power intended to be delivered to the most distant machines will have become lost in a maze of shafting and belting.

It is no uncommon thing in plants of this character to find a friction load of 75 percent of the total power. Where the plant is motor driven throughout and power is supplied from generating equipment in connection with the factory, provision must be made in the original power house installation for this growth. If this has

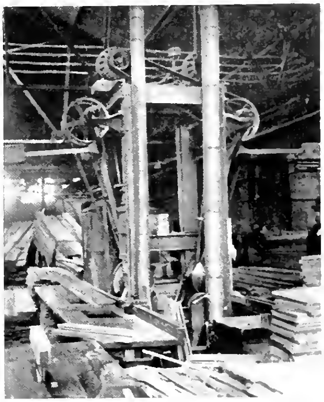

FIG. 4—A NOVEL METHOD OF MOUNTING TWO SWING SAWS AND DRIVING MOTORS

The material in this plant comes from resaws and finishing machines shown in background past a row of swing saws arranged as shown in this picture, where the material is cut to the desired length for further use.

not been done a serious condition is very apt to arise requiring unnecessary expense in order to correct this deficiency. It is at this point that many plants decide to

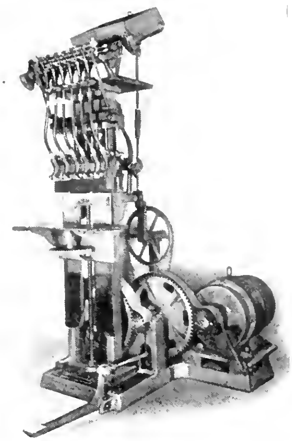

FIG. 5—BOX NAILING MACHINE DRIVEN BY INDIVIDUAL DIRECT-CURRENT MOTOR

This direct-current motor has been made absolutely safe for use in woodworking plants by totally enclosing with sheet-iron covers over front and rear brackets. This is a two hp motor running at 1200 r.p.m.

make a trial of purchased power and eventually discard their own generating equipment.

Aside from the problems incident to the building and power equipment to be considered with the original installation, there are a large number of other advantages to be obtained from motor drive regardless of the supply of power, which can be considered briefly:—

From the owners' or directors' standpoint, the most successful manager of a plant is one who can show the largest satisfactory output with the smallest outlay. In

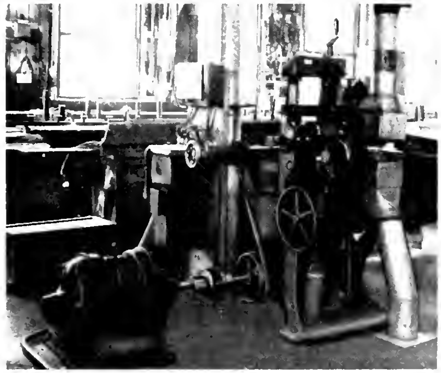

FIG. 6—SASH AND DOOR TENONER FLEXIBLE COUPLING TO A 7.5 HP, 855 R.P.M. MOTOR

the woodworking industry the cost of power bears a very appreciable ratio to the total cost of the finished product. It is in production, however, that the use of motor drive usually shows its greatest value. Maximum production cannot be obtained with slipping belts or under conditions where the operation of one or two heavy machines will materially reduce the operating speeds of the remaining machines in the factory. With

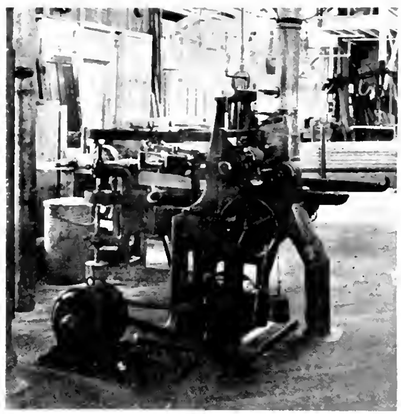

FIG. 7—SASH AND DOOR TENONER DRIVEN THROUGH A FLEXIBLE CHAIN BY A FIVE HP, 1735 R.P.M. MOTOR

Figs. 6 and 7 show two satisfactory methods of driving a tenoner. The first cost of the higher speed motor and chain drive will be from 20 to 30 percent less than the cost of a slow-speed motor with coupling on this particular size, but the life of the chain is limited, and in the end the coupled drive will prove cheaper.

each of the machines driven as an independent unit, the operating speeds, and therefore the production, may be maintained at a maximum.

In order to secure the maximum and most efficient production from any factory the various machines must be so arranged as to accommodate the material going through with the least possible handling, and this condition can only be obtained through individual motor drive which allows locating the machines without reference to operation from existing line shafting.

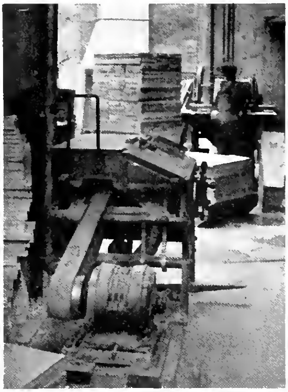

FIG. 8—A SATISFACTORY BELT DRIVE FROM A THREE HP, 1730 R.P.M. SQUIRREL-CAGE MOTOR TO A HAND HOLE CUTTER IN BOX FACTORY

The high operating speeds of woodworking machines permits the elimination of all unnecessary countershafts and belts, and in many cases allows the direct coupling of high-speed motors to the operating parts of the machines. This is particularly exemplified in the use of 3600 r.p.m. motors, direct connected to planer and matcher heads, the coupling of 900 and 1200 r.p.m. motors to the machine countershafts of four-side moulders, the connection of 1200 and 1800 r.p.m. motors directly to saw arbors, and the mounting of small motors in the head stocks of wood lathes.

FIG. 9—A CONVENIENT ARRANGEMENT FOR MOUNTING A THREE HP, 1730 R.P.M. SQUIRREL-CAGE MOTOR FOR DRIVING VERTICAL BELT SANDER

The individual drive on this machine allows it being placed in the most advantageous position in the finishing department without reference to any line shaft.

With individual motor drive each machine uses power only when it is actually in service. With shaft drive there is always the continual friction loss of a considerable section of line shafting and a number of belts which is directly chargeable to each machine. Motor drive allows the up-to-date manager to check the power consumption of his different departments against production in that department, as well as the power consumption of the individual machines. These figures often show unnecessary losses, which may be easily remedied when their existence is evidenced.

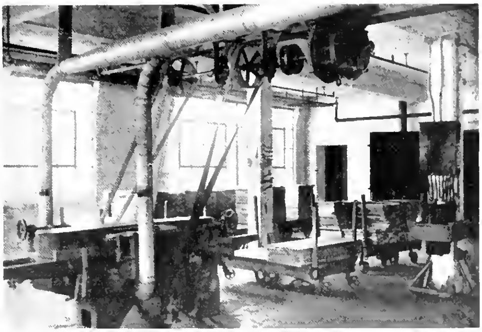

FIG. 10—A 10 HP, 850 R.P.M. SQUIRREL-CAGE MOTOR, FLEXIBLY COUPLED TO THE END OF THE COUNTERSHAFT OF A CONTINUOUS SPEED GLUE JOINTER

With reference to the selection of motors to drive the various machines, the long experience of the leading electrical manufacturers, as well as the builders of the woodworking machines themselves, has enabled these companies to determine very closely the size and type of motor best suited to any given application. In making these applications it should be borne in mind that the same machine under different conditions will often require different sizes of motors and consume different quantities of power. In asking for information, therefore, as to what motor is best for any given machine, as complete information as possible should be given as to the size, type and make of machine to be driven, the nature of the work to be performed on the machine, and the various classes of material to be worked.

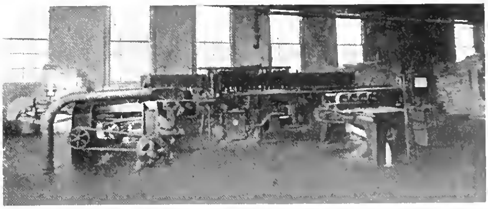

FIG. 11—A LINDERMAN FOUR-FOOT GLUE JOINTER DRIVEN BY TWO MOTORS, ONE OF 15 HP, 1740 R.P.M., AND ONE OF 10 HP, 1740 R.P.M.

A question which is very often a vital issue in deciding for or against purchasing power is the disposal of

the waste wood, shavings and sawdust which accumulate. The solution of this question is in every case a local one. In the first place, it is always policy for the woodworking plant to reduce its small pieces of wood waste to useful articles wherever possible, such as handles, brush backs, etc. In almost every case the shavings may be baled and sold for any one of a large variety of uses. The sawdust, of which there is very little in finishing plants may also be sold separately. Many cases are on record where the revenue from baled shavings has more than paid for the purchased power. The fact that baled shavings in packages weighing approximately 125 lbs. will bring at the mill from 15 to 25 cents per bale is convincing evidence that this is very expensive fuel. These bales may be produced at the plant at a cost of less than five cents per bale, exclusive of the cost of the shavings. With a net profit of 15 cents per bale one ton would be worth $2.40. Assuming that these shavings have a heating value of four-tenths that of coal of an equal weight, burning these shavings would be the equivalent of burning coal at six dollars per ton.

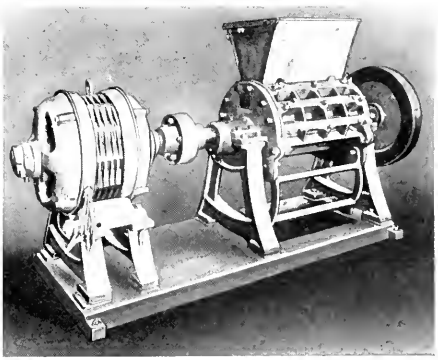

FIG. 12—A 10 HP, SQUIRREL-CAGE MOTOR DIRECT CONNECTED TO A HOG

For reducing wood waste to suitable size for convenient handling.

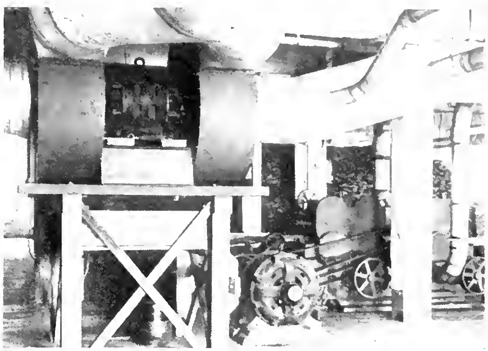

FIG. 13—A 35 HP, 1160 R.P.M. SQUIRREL-CAGE MOTOR WITH DOUBLE EXTENDED SHAFT, DRIVING DOUBLE EXHAUST FAN

The chemical utilization of waste products from small mills has not up to the present time been worked out satisfactorily. Very often a number of different woods are used in the same mill. Different woods require different treatment and produce different by-products. It is, therefore, useless to think of keeping the refuse from the various woods separate and subjecting each to the proper treatment. Where large amounts of sawmill refuse are available it is possible to put into effect processes such as are used for producing by-products from timber cut for that purpose. Reference to the method of handling this subject may be found in a number of books and pamphlets.* A department of the Forest Service, United States Department of Agriculture, has recently been organized, known as the Wood Waste Exchange. Mills having materials for sale may list them with this department, which issues a bulletin every two weeks, distributed to prospective purchasers. Likewise, a list of buyers is distributed to the mills requesting this service.

FIG. 14—A GROUP OF INDIVIDUALLY DRIVEN MACHINES IN SMALL WOODWORKING PLANT

This group shows a 25 hp, 1755 r.p.m. squirrel-cage motor belted to a 36 inch exhaust fan, a five hp, 1755 r.p.m. squirrel-cage motor belted to a nine-inch matcher, and a 10 hp, 1740 r.p.m. squirrel-cage motor belted to a single-head planer.

*"Chemical Utilization of Southern Pine Waste," J. S. Bates (Industrial and Educational Press, Montreal).

"Utilization of Wood Waste by Distillation," W. B. Harper.

"Utilization of Wood Waste," by E. Hubbard; trans. from German by M. J. Salter (Scott, Greenwood & Co., London).

Circular No. 0, "Chemical Methods for Utilizing Wood Wastes," Department of Interior of Canada, Forestry Branch, Montreal, Canada.

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Electrical Equipment for Motion Picture Machines

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THAT the motion picture theater is a permanent institution is evidenced by the developments during the past two years in particular. The small motion picture theaters have increased in number and many of them have been enlarged and very materially improved. Numerous picture theaters have been built which are second to none of the legitimate theaters with respect to size and appointments of the exterior and interior. The picture theaters have not progressed more rapidly than have the productions which are now depicted on the screen and which comprise feature plays costing hundreds of thousands of dollars to produce and which employ the best of theatrical talent as principals. The picture-producing interests have invested fabulous sums in permanent studios fitted with every conceivable contrivance necessary for the production of practically any play and the innumerable feature incidents which occur in the lives of any and all peoples of this world.

IN THE early days of the motion picture industry the source of light was in many cases of the well-known calcium type. Gradually, however, it became necessary to use some source of illumination which would develop a light of greater intensity. It was for this reason, primarily, that the electric arc was adopted for motion picture work.

In 1914 one authority estimated that there was installed in this country a total of 60 000 kw of motion picture machines. By this time, no doubt, this figure is very low. An average motion picture arc lamp (using direct current) consumes about two kilowatts, but owing to the losses in various necessary devices interposed between the arc lamp and the supply circuit there is required from the supply line approximately 4.5 kw per machine. The average picture theater operating eight hours a day, 312 days a year, will consume in a motion picture machine alone approximately $350 worth of electricity, based on a rate of three cents per kilowatt-hour. The power used in the arc will be, as a rule, at least one-half of the total power used in the theater, including that used for illuminating lamps, fan motors, etc.

In most localities the commercial source of electrical energy is a 110 or a 220 volt supply circuit, either direct or alternating current. An alternating-current arc can be operated most successfully at a potential not much in excess of 30 to 35 volts, and a direct-current open arc can be operated most successfully at a potential not much in excess of 50 to 60 volts. It was, therefore, for a time customary to use a large resistance in series with each arc to reduce the line voltage. This method is obviously very inefficient and, furthermore, the heat generated in the resistor is very objectionable. Hence auto-transformers (commonly known as economy coils) were introduced. This type of apparatus, although reducing the power bills and eliminating the objectionable heating feature, did not permit the production of as good results on the screen as could be obtained where the rheostat was used and power obtained from a direct-current circuit.

Superiority of Direct Current — Direct current is much more satisfactory and effective than alternating current for a projecting arc lamp. First, the light produced is of a much better quality, as the greenish tinge is entirely absent; therefore, the light more nearly approaches that of sunlight. Second, the light is much easier to focus, due to the fact that the arc is much steadier and does not have a tendency to travel around the periphery of the electrodes; also the arc forms a crater in the positive electrode which produces approximately 85 percent of the useful light, 10 percent being produced by the negative electrode and 5 percent by the arc stream. Third, the current in an alternating-current arc reverses and becomes zero twice during each cycle, thus producing a decided flicker, which may be observed on the screen if the revolving shutter of the motion picture machine is not properly designed or operated at the correct speed. Fourth, there is no crater formed when alternating current is used, and hence the light must be obtained from both electrodes and from the arc stream. As a result, the light is not concentrated in a point, and hence cannot be as easily focused. Owing to these characteristics and the cooling effect when the current is zero, approximately three times as much alternating current is required to produce an illumination equivalent to that produced by a given direct current.

Direct-Current Apparatus—Because of the physical advantages of the direct-current arc, numerous types of apparatus have been introduced which will supply direct current at a reduced potential. These comprise rotary converters, mercury arc rectifiers, mechanical rectifiers and motor-generator sets of various mechanical and electrical characteristics.

The electric arc possesses a unique electrical characteristic, namely, a negative resistance coefficient. In other words, as the current in the arc increases, the resistance, and hence the potential across the arc, decreases. It is evident, therefore, that if the arc were connected to a constant potential circuit having an infinite capacity, the current through the circuit would tend to build up to infinity. Therefore, it is necessary to provide characteristics in the apparatus supplying power to the arc, such that the arc current will be maintained practically constant.

The ideal apparatus for this service is a strictly constant-current generator driven by a suitable motor or engine. This type of generator, however, is comparatively expensive to build and, furthermore, in the usual forms is quite complicated. There are several generators on the market which are designed for characteristics approaching those of a strictly constant-current machine. These generators are provided with special field windings and armature windings having a comparatively high reactance, which results in an extremely drooping voltage characteristic such that the generator will develop about 55 volts at full-load current and will not be damaged when short-circuited, because the current will never be much in excess of full rated load. Constant potential generators and rotary converters are also designed to develop 70 to 80 volts direct current, a ballast rheostat being interposed in the circuit to each arc lamp. This ballast resistance neutralizes the negative resistance characteristic of the arc so that the current remains appreciably constant at all times. For this service mercury arc rectifiers are also supplied. The direct current produced by the mercury arc rectifier is maintained practically constant by the reactance of the auto-transformers which are used for supplying power to the bulb. This makes the rectifier inherently more efficient than if a ballast resistance is used in the direct-current circuit; furthermore, the apparatus is self-contained.

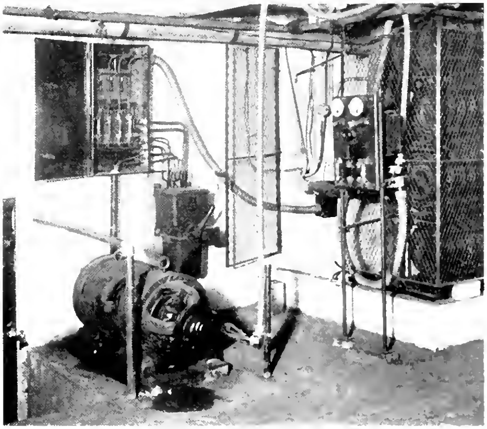


FIG. 1—TYPICAL MOTOR-GENERATOR SET AND CONTROL PANEL
For operating duplicate motion picture equipment. Set located under the stage of a theater.

Types of Direct-Current Apparatus—The majority of theaters projecting feature films desire to have a continuous performance, which is obtained by using two motion picture machines alternately. Before the end of one film is reached, the second lamp will be started up and made ready for projecting pictures. This requires either duplicate generating equipment for the two motion picture machines or generating equipment which will successfully carry large overloads for a short period of time; also the potential of the generator must not be appreciably affected at the instant when the arc is struck. The potential of the generator must also be practically independent of the usual commercial speed variations of the motive power, such as would be produced by a voltage variation of the supply circuit to the motor driving the generator.

For any installation using two machines alternately very successful operation will be obtained by using a motor-generator set and a ballast resistor in series with each arc lamp, the generator to be flat or slightly over-compounded and to develop 75 volts at full-load. Neither the rotary converter nor the shunt-wound generator having a drooping voltage characteristic is as satisfactory for several reasons. First, the voltage of the rotary converter will vary almost directly with changes in the alternating supply voltage, thus resulting in fluctuations of the arc. Second, the actual overall efficiency of the rotary converter, including auto-transformers and ballast rheostats, is not greater, and in many cases is actually less, than the overall efficiency (including ballast rheostats) of a motor-generator set composed of a compound-wound 75 volt generator and a polyphase, 60 cycle induction motor. Third, the voltage of the shunt-wound generator of the drooping voltage characteristic type is quite sensitive to speed fluctuations. If, therefore, such a generator is driven by a motor whose speed varies perceptibly the set will not give perfect satisfaction. This characteristic is particularly objectionable where the motor is supplied with power from a trolley line. Fourth, when two motion picture machines are used alternately it is necessary to provide a series field and ballast rheostats for the shunt-wound drooping voltage generator. Just before striking the second arc the operator must manipulate a switch on the control panel, which makes the series field operative and at the same time introduces the ballast resistors in the circuits of the arc lamps. This then produces practically the same characteristics as are obtained with the compound-wound sets. For the 75 volt, compound-wound sets the entire control consists of a single switch mounted on each motion picture machine within convenient reach of the operator.

FIG. 2—TYPICAL MOTOR-GENERATOR EQUIPMENT
Located in balcony of motion picture theater.

In addition to the requirements which have been cited, it is advisable that each 75 volt, compound-wound generator be provided with properly designed commutating poles to insure perfect commutation when the machine is subjected to the severe overload imposed at the instant of striking an arc, particularly when the generator is already supplying current to a motion picture machine in operation.

For installations requiring arc currents within the limits for which the mercury arc rectifier is built, the features of securing the required drooping characteristics by reactance instead of resistance, and of delivering a direct current to the arc without the use of rotating parts, make this apparatus inherently an efficient and simple equipment for the service. Partly offsetting these fundamental advantages which arise from the nature of the apparatus is a secondary and minor characteristic arising from the manner of securing the drooping characteristic. It is impossible to operate two arcs simultaneously from a rectifier, not because of any lack of overload capacity, but because the stabilizing reactance is in the primary circuit, and hence not between the arc and the transformer. For this reason separate stabilizing reactances cannot be used for the two arcs, and no means of balancing the current in the two arcs is available. In fact, if the carbons of one arc are closed while the other arc is operating the current will merely be transferred from one to the other. This fact suggests a method of using a single rectifier equipment to operate two lamps, a method now in quite wide use and entirely successful. The arc is merely "stolen" from the machine with the completed reel by starting the arc in the machine to be used. This same object has been accomplished by another scheme in case the operator insists on having his arc started a short time before starting the reel. In this case the picture is shown practically complete on direct current from the rectifier, and finished on alternating current, while the second arc is being heated by direct current from the rectifier. The change-over is made by reversing a double-throw switch.

Current Rating—When a new motion picture theater is contemplated the question naturally arises,—how much current is required for the arc lamp? The light (produced by the current) which must be developed by the arc depends upon a number of factors, as:—

1—Size or area of the picture.
2—The color-producing scheme, such as the Kinemacolor, and tinted films.
3—Length of throw in feet from motion picture machine to the screen.
4—The density of the films.
5—The material of the screen.
6—The design of the revolving shutter on the motion picture machine.
7—The quality of the condensing and objective or projecting lenses.
8—Size of carbons, their adjustment and size of "spot."
9—The amount of general illumination in the theater; also the location and arrangement of lighting fixtures.

Size of the Picture—The size of the picture projected is probably the most important factor of those cited. It is fixed by the aperture of the motion picture machine; by the focal length of the objective or projecting lenses and by the distance from the objective lenses to the screen. Most motion picture machines have an aperture approximately 11/16 in. high by 15/16 in. wide and, therefore, the height and width of the picture projected will be proportional to 11 and 15, respectively. Assume for an example an installation wherein the picture projected is 10 ft. high and 13.6 ft. wide. If the objective lenses are replaced so that the picture is enlarged to 13 ft. in height, then the area of the picture is 70 percent greater than it was formerly, although the height has only been increased 30 percent. Therefore, 70 percent more light must be developed to produce the same brilliancy on the screen. The size of the picture required depends upon the size of the theater, both width and depth, and also upon the particular desires of the manager.

Colored Pictures—Where revolving colored filters are used for producing color effects, such as in the Kinemacolor scheme, only a certain portion of the light spectrum developed by the lamp reaches the screen. For this reason, therefore, a much more intense light is required, varying from two to three times that required for ordinary black and white projection. Where tinted films are used the required amount of light is increased, but not to such a degree as just cited for the Kinemacolor scheme.

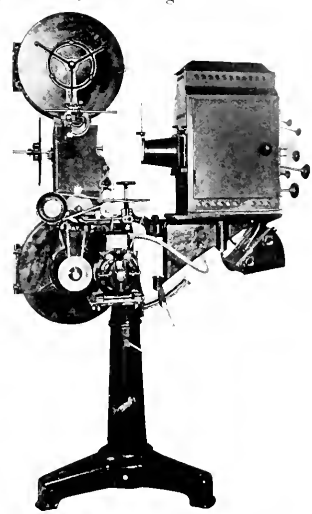


FIG. 3—TYPICAL MOTION PICTURE PROJECTOR, OPERATED BY ONE-TWELFTH HORSE-POWER CONSTANT-SPEED MOTOR

Adjustment of film speed is obtained by an adjustable speed friction drive covering a range corresponding to 25 to 100 r.p.m. of manual crank.

Length of Throw—There is no general agreement as to the effect of the distance from the objective lenses to the screen upon the amount of light which must be developed by the arc for a given illumination upon the screen. In fact, many contend that where the length of throw is between 50 and 125 feet, there is very little difference for a given motion picture machine projecting a picture of the same dimensions in each instance. Theoretically, this is undoubtedly true. However, due to the fact that objective lenses are not perfect, there is a diffusion and dispersion of the projected light which is more evident at greater distances. Furthermore, in the average theater the air is always more or less dusty and, in fact, in some theaters where smoking is permitted, the air becomes quite dense at times. It has been found,

therefore, that the length of throw does actually affect the quantity of light which must be developed.

Density of Films—There is a considerable difference in density produced during the process of developing the films. It is obvious that the amount of light required for a dense film will be greater than for a more transparent one. However, the light used under ordinary conditions is generally found sufficient to give satisfactory results with almost any commercial film.

Type of Screen—Seeing a motion picture is entirely dependent upon the light which is reflected from the screen into the eyes of the observer. It is obvious, therefore, that if the percentage of the total light reflected in all directions (by the so-called diffuse reflection) is increased, then the light developed may be decreased and yet produce the same result. Therefore, when a plain white mat screen of canvas is used, a greater amount of light must be developed than if some one of the semi-mirror screens is used. Screens which have a yellow or gold-colored tint usually do not require as much illumination, simply due to the fact that a light having a yellow or orange tint gives the effect upon the eye of being relatively much more brilliant than a white light of equal intensity in candle-power.

Design of Revolving Shutter—The design of the revolving shutter on the motion picture machine materially affects the amount of light which must be developed, because shutters of various types permit from 50 to 65 percent of the light passing through the objective lenses to reach the screen. The flicker is eliminated to a greater degree, however, when a properly designed shutter in the 50 percent class is used.

Quality of Condensing and Objective Lenses—Not only the quality of the condensing and projecting lenses, but also the size of the condensing lenses, affects materially the quantity of light which must be developed. The quality of the lenses determines the amount of light lost by absorption and diffusion. The size and design of the condensing lenses determines the percentage of the total light developed, which is collected and concentrated for the "spot."

Size of Carbons and Adjustments—When direct current is used a crater is formed in the upper or positive electrode. This crater is a molten spot of carbon, which is at a temperature of nearly 6500 degrees F. This crater is the hottest portion of the arc, as the negative electrode seldom, if ever, reaches a temperature in excess of 4500 degrees F. The carbons must be of a size best suited to the current required, because if the positive carbon, particularly, is too large, an excessively large current is required to heat it sufficiently to produce the crater from which the major portion of the light is secured. On the other hand, if the carbons are too small, sufficient light cannot be produced. Furthermore, in this latter instance, difficulty will also be experienced if the operator attempts to secure a brighter light by adjusting the carbons more closely together, as this will result in a hissing and sputtering arc, which is unstable and is unsatisfactory for projection work. The only alternative in such a case is to operate the arc at abnormally high potentials, varying from 60 to 70 volts, under which conditions a larger current can be used. This is not satisfactory, however, because the arc voltage is too near that of the usual generating equipment, and hence the arc has a tendency to become unstable, requiring very frequent adjustment of the carbons.

Experience has indicated that carbons which give most satisfactory results for various direct currents are as follows:—

Amperes through Arc	Diameter of Carbons—Inches.	
	Upper.	Lower.
25 to 30	5/8	1/2
40 to 60	3/4	5/8
70 to 100	1	3/4

The lower carbon can be smaller than the upper, as it is subjected to a much lower temperature, and hence is consumed much more slowly. With inclined carbons, the lower electrode then interferes less with the light.

The two carbons are usually adjusted in the holders at an angle of 15 to 30 degrees from the perpendicular to the axis of projection, the positive carbon being located slightly behind the negative. This adjustment results in turning the plane of the crater more nearly perpendicular to the axis of projection, and gives the condensing lenses the best opportunity to collect the light. The size of the "spot" should, of course, be no larger than is absolutely required to eliminate dark corners, because all light developed which does not hit the film is wasted.

General Interior Illumination—The effect of brilliant pictures will be materially modified if the interior of the theater is illuminated more than is absolutely required. It is desirable, therefore, to keep the general illumination, especially in the front of the hall, to a minimum consistent with the safety and convenience of the patrons, and to keep all light sources out of the direct line of vision.

Empirical Formula—The factors which have been considered undoubtedly seem quite complicated. In actual practice, however, the selection of the proper size generator or motor-generator set is not nearly as difficult as it appears. A study of the average conditions existing in the majority of theaters has led to the development of an empirical formula, which has proven reasonably accurate for practically any installation wherein the general illumination is not excessive and a plain white canvas screen or its equivalent is used. The formula is:—

$$I = \frac{A + 2L}{10}$$

where A = area of picture in square feet.
L = length of throw in feet.
I = direct current in amperes required through the arc.

For installations wherein semi-mirror screens or screens of a similar character are used the constant 10 should be increased to 12.5.

The Development and Use of the Mazda C Lamp

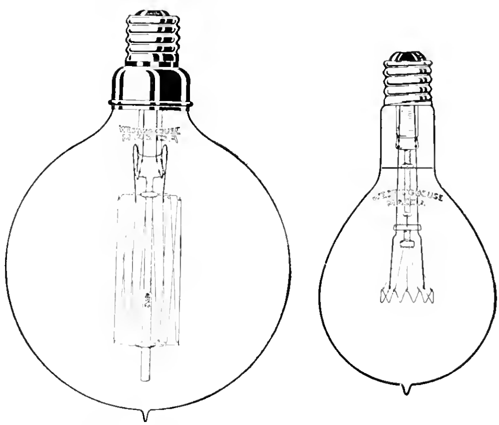
W. A. McKay
Westinghouse Lamp Company

THE DEVELOPMENT of the Mazda "C" lamp since the first lamps of the type appeared on the market in the early part of 1914 has been very rapid and the field of application of these lamps has been broadened as the result of experimental work and trial until they have now practically superseded such illuminants as the enclosed carbon arc lamp and are being used very extensively in fields formerly held by other types of illuminants.

THE Mazda "C" lamp resulted from the discovery by Dr. Irving Langmuier that the rate of disintegration or evaporation of the incandescent tungsten filament could be materially reduced by operating it in an atmosphere of chemically inert gas instead of in a vacuum. This discovery was of great importance, as the useful life of a tungsten lamp is determined by the rate at which the filament disintegrates. In the first place the disintegration progresses in time to such an extent that the filament fails, and in the second place the metallic tungsten thrown off from the filament is deposited on the bulb and the deposit eventually becomes so dense that the light output from the lamp is seriously reduced.

Prior to Dr. Langmuir's discovery much had been accomplished in the vacuum type of lamp by the use of chemicals known as "getters," which combined with the deposit and changed its color to white or yellowish white and so reduced the amount of light absorbed. It seemed, however, that the limit had been reached in lamps which operated at an efficiency of about 11 lumens per watt, and the prospects of attaining higher efficiencies with a tungsten filament operating in a vacuum did not seem very promising. The lamp engineers, therefore, foreseeing the possibility of further increasing the efficiency of the tungsten filament lamp by operating the filament in an atmosphere of inert gas instead of in a vacuum, devoted their attention to the production of commercial lamps of the gas-filled type. After much experimental work a satisfactory type of construction was developed, and in the early part of 1914 several sizes of street series lamps and the 750 watt and 1000 watt multiple lamps were placed on the market. In developing these lamps many problems not hitherto encountered in lamp design had to be solved. The most important of these was to reduce the energy losses caused by the presence of the gas in the bulb, and this was accomplished by winding the filament in the form of a helical coil, thus reducing the area exposed to the cooling action of the gas and making the bulb as small as possible and so reducing the radiating surface.

Although the use of the gas resulted in the loss of a certain amount of energy it also reduced the rate at which the filament disintegrated to such an extent that it was found possible to raise the operating temperature of the filament to a point at which the greatly increased light output more than compensated for the energy losses and the efficiency of the lamp was much higher than that of the vacuum type. The gas-filled Mazda lamp progressed very rapidly, and before the end of 1914 most of the street series lamps were made in this type and the line of multiple lamps was extended to include 500, 400, 300 and 200 watt lamps.



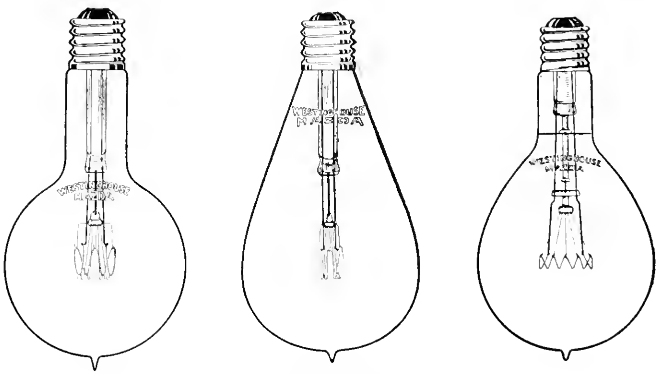
500 Watt Mazda B Lamp — 500 Watt Mazda C Lamp

FIG. 1—RELATIVE SIZES AND DIFFERENCES IN CONSTRUCTION

Since there were now two types of Mazda lamps it became necessary to distinguish between them, and the names Mazda "B," to describe the vacuum type, and Mazda "C," to describe the non-vacuum, or gas-filled type, were adopted. In the course of the development of the Mazda "C" lamp experiments were made with several types of bulbs and, finally, in the early part of 1915, the present pear-shaped bulb, Fig. 2, was adopted. The long neck of this bulb, which acts as a cooling chamber for the heated gas is partially closed in the larger sizes by a mica disc to prevent the heated gas from coming into direct contact with the base.

The development of new types of Mazda "C" lamps continued, and in the early part of 1915 the 100 watt multiple lamp was placed on the market, and on May 1

of this year the 75 watt lamp, Fig. 3, was announced. Beside the more familiar types of multiple and series lamps, special types have been developed for various services, and new types are continually being developed to meet the demand resulting from the very marked advantages of this type of lamp in many kinds of work.



a—Round Bulb *b*—Straight Side Bulb *c*—Pear-Shaped Bulb

FIG. 2—DEVELOPMENT OF BULB

The use of the Mazda "C" lamp has resulted in an increase in the amount of light used for all kinds of work and has had a very marked effect on the design of street, industrial and commercial lighting systems. Before the advent of the Mazda "C" lamp street lighting installations consisted largely of arc lamps of various types and some Mazda "B" lamps. It soon became evident, however, that the Mazda "C" lamp offered many advantages in the way of lower initial cost of units, greater flexibility, because of the wider range in sizes of lamps which are available for operation on the same system, and increased capacity on alternating-current series systems, because of the high power-factor of the units, which have resulted in the widespread use of this type of lamp for street lighting.

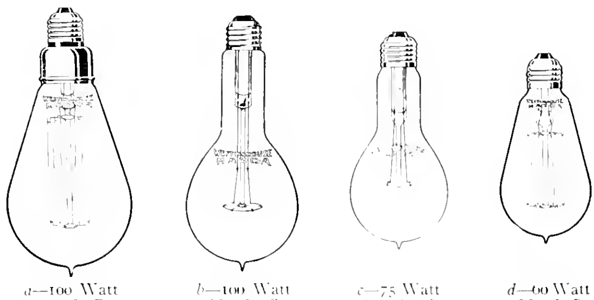
In the industrial lighting field there has been a great increase in the use of artificial lighting, and Mazda "C" lamps are being used in great numbers in this class of work. The larger sizes used in properly designed reflectors provide very satisfactory illumination for erecting sheds, foundries, railroad yards, etc., where the units must be placed high above the work: while the smaller sizes are used in the general illumination of machine shops, textile mills, etc.

It is, however, in the field of commercial lighting that the influence of the Mazda "C" lamp is most apparent. The use of this type of lamp has resulted not only in an increase in the intensity of illumination, but also in greater attention being devoted to the requirements of good lighting. There has been a great increase in the use of semi-indirect and totally indirect lighting in stores, etc., and it is evident that more attention is being given to getting the units up out of the field of vision and protecting the eyes from the glare of bare filaments.

A notable development in the lighting field has been the increased use of various media for modifying the color of the light in order to secure light of a particular spectral quality or to obtain certain desired effects in the lighting of interiors, etc., to which the Mazda "C" lamp lends itself particularly well because of its high efficiency and the continuous character of its spectrum.

Artificial daylight units employing Mazda "C" lamps are being widely used where light of the same spectral quality as daylight is required, as in color matching, etc. Formerly those engaged in such work were dependent on daylight, which is available only for a few hours in the day. Now, however, such work may be done anywhere and at any time by means of daylight units employing the Mazda "C" lamp, the operating cost of which is about the same as that of the old carbon incandescent lamp. Light approximating daylight in quality is also used in the general illumination of drygoods stores, etc., and in the illumination of show windows.

In stage lighting and similar work the Mazda "C" lamp has met with great success. The ordinary types are used in the borders, etc., while lamps with concentrated filaments are used in spot and flood lamps, replacing the arc lamps which were formerly used for this purpose. Such units are very much more satisfactory than those employing arc lamps, since they do not require the attention that the arc lamp requires, the light does not flicker, the annoying noise of the arc is eliminated and, while formerly one man was required to every two arc lamps, one man may now operate several of the Mazda "C" lamp units.



a—100 Watt Mazda B *b*—100 Watt Mazda C *c*—75 Watt Mazda C *d*—60 Watt Mazda B

FIG. 3—100, 75 AND 60 WATT MAZDA LAMPS

For photographic work the Mazda "C" lamp provides an inexpensive, efficient illuminant, the light of

which is of constant quality, readily controlled and available at all times. For this class of work special lamps have been developed, the light of which closely approximates that of daylight in quality and actinic value and may, therefore, be used in daylight studios to reinforce daylight during the hours when the intensity of daylight is not sufficient for rapid work. Such units, however, render the photographer independent of daylight and make it possible to set up studios in locations in which daylight is not available and thereby secure results equal to those obtained under the best natural lighting conditions. Mazda "C" lamps in reflectors have been used in making photographs of interiors, etc., in preference to flashlights, and it is probable that they will come into wide use for this purpose, particularly in home portraiture, etc. Installations of Mazda "C" lamps are also being used with very satisfactory results in the making of motion pictures, and it is probable that there will be a greater use of this lamp for such work in the future.

FIG. 4—LAKE SHORE DRIVE, CHICAGO, ILL., LIGHTED BY MAZDA C LAMPS

Although there had been some instances of the illumination of buildings, signs, etc., by light sources placed at a distance, before the advent of the Mazda "C" lamp, this form of lighting, now known generally as flood-

FIG. 5—RAILROAD CLASSIFICATION YARD LIGHTED BY MAZDA C LAMPS

lighting, had not made any great progress. The concentrated filament Mazda "C" lamp, however, proved very well adapted for use in reflectors designed to concentrate the light from the source into narrow high intensity beams and made possible the present very wide development of this form of lighting.

The concentrated filament Mazda "C" lamp has also proved very satisfactory in small stereopticon and motion picture machines, and the greater number of the machines now sold are equipped with this type of lamp.

With reference to use of Mazda "C" lamps, the user should be guided by the recommendation of the manufacturer regarding the position in which they should be burned, ventilation of fixtures, etc. The following rules with regard to the position in which Mazda "C" lamps may be burned should be followed:—

a—Multiple Mazda "C" 200 to 1000 watt lamps should be operated in the tip-down position. If necessary, the lamps may be inclined at an angle not to exceed 25 degrees from the vertical, but should never be burned in the tip-up or horizontal positions.

b—The 75 and 100 watt multiple lamps may be burned in any position, but the best results are obtained in the tip-down position.

c—Street series lamps generally are designed to operate in the tip-down position, although those types which have a straight filament may also be operated in the tip-up position.

d—Stereopticon and flood-lighting lamps may be operated in any but vertically base-up position.

With reference to ventilation, it is essential that sufficient ventilation, to prevent overheating, be provided

FIG. 6—INDIRECT LIGHTING OF DRYGOODS STORE WITH MAZDA C LAMPS

in reflectors, enclosing globes, etc., designed for use with Mazda "C" lamps, and this type of lamp should not be used except under such conditions.

Two-Speed Alternating-Current Elevator Motors

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THE use of alternating-current for operating elevators has been limited to car speeds of a maximum of 200 to 250 feet per minute, because the alternating-current motor was a single-speed machine and dynamic braking and slow-down could not be accomplished without installing a motor-generator set and complicating the control, thus making the installation expensive. It was also difficult at high speeds to accomplish smooth acceleration with a single-speed motor. The stopping of the car depended entirely on the electrically-operated mechanical brake, so that at higher speeds it was impossible to obtain a smooth stop and the wear and tear on the brake was excessive. To overcome these objections and to make an alternating-current motor that was practical for operating elevators at car speeds of 300 to 400 feet per minute a two-speed elevator motor has been developed.

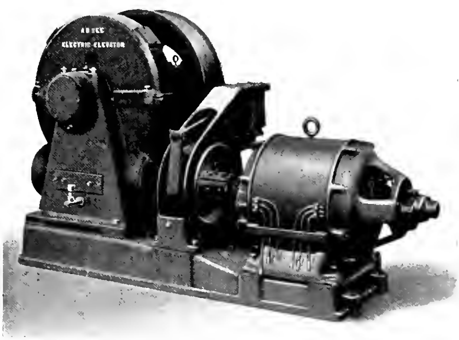

FIG. 1—TWO-SPEED WESTINGHOUSE ALTERNATING-CURRENT ELEVATOR MOTOR DRIVING SINGLE-GEARED TRACTION ELEVATOR WINDING MACHINE

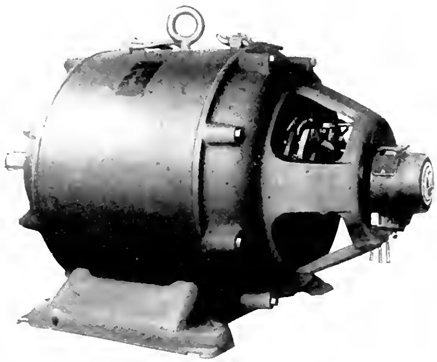

FIG. 2—TWO-SPEED WESTINGHOUSE ALTERNATING-CURRENT ELEVATOR MOTOR COMPLETE

The distinctive feature of the motor is the use of two independent windings in both the stator and the rotor. The windings on a 60 cycle circuit give motor speeds of 250 and 840 revolutions per minute. In starting, the 250 r.p.m. stator winding is connected to the circuit. After the motor gets up to this speed, which would correspond to a car speed of 120 feet per minute on an elevator having a maximum speed of 400 feet per minute, the connections are automatically changed to the 840 r.p.m. winding with resistance in the rotor circuit. Next, this resistance is cut out automatically, bringing the motor up to the full speed of 840 r.p.m. and the car to 400 feet per minute.

In slowing down, the operator reverses the sequence of connections so that the 250 r.p.m. winding is in the circuit. But at the instant this is done the motor is running at a higher speed than the synchronous speed for this connection; and as an induction motor driven above synchronism acts as a generator, it provides an electrical braking action which quickly retards the motion and reduces the motor speed to synchronism. In this case it would reduce the elevator car speed to 120 feet per minute. The operator then throws the car switch to the off position, disconnecting the motor from the line and applying the electrically-operated mechanical brake, bringing the car easily and smoothly to rest. Both rotor windings are connected to the same slip rings, so that only three collector rings are necessary. In operation the low-speed rotor winding responds only when the low-speed stator connection is made, and the high-speed rotor winding is active only when the high-speed stator connection is made.

The motor develops the high starting torque which is required in elevator service with a starting current only 50 percent above the current at full speed with full load. The rotor is small in diameter, thus producing the low flywheel effect which is necessary in a service requiring frequent starting, stopping and reversing. The motor is very quiet in operation.

The controller, Fig. 4, consists of a number of magnetically-operated switches and relays mounted on a slate panel and operated by a car switch located in the elevator car. When the car switch is thrown to either the full up or down position the controller connects the low-speed motor winding to the line with resistance in the rotor circuit. As the motor accelerates this resist-

ance is automatically cut out by magnet switches, the rate of whose operation is controlled by series current limit relays, bringing the motor up to the full speed of the low-speed winding. A change-over switch then closes, opening the low-speed winding and impressing voltage on the high-speed winding with resistance in the rotor circuit. This transition is made so smoothly that it cannot be sensed in the elevator car. The resistance is then cut out automatically as above, bringing the motor

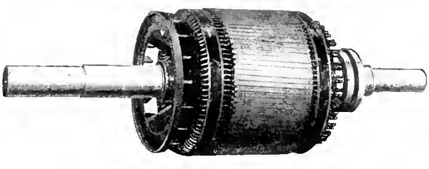

FIG. 3—ROTOR

and car to full speed. Both acceleration and retardation are accomplished smoothly without any shock or jar in the car. The car switch provides for two running speeds in each direction. The same safety devices, such as hatchway and car limit switches, slack cable switches, emergency car switch, etc., which are used with high-speed elevators driven by direct-current motors, can be used with this equipment.

The application of this type of motor and control will enable the central stations to supply alternating current to elevators operating in hotels, department stores, etc.,

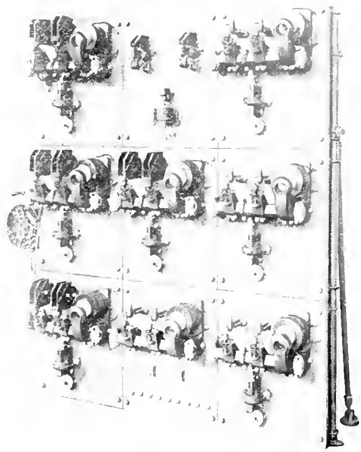

FIG. 4—TWO-SPEED WESTINGHOUSE ALTERNATING-CURRENT ELEVATOR CONTROL

in the downtown districts, where in the past it has been necessary to supply direct current.

Twenty-two Thousand Volt Distributing Transformers

E. G. REED

DELIVERING electrical current to the consumer through small step-down transformers connected to primary distributing circuits of 6600, 11 000, 13 200 and 16 500 volts is common practice. During the past few years there has been an increasing tendency to distribute current in the same manner from transmission circuits of 22 000 and 33 000 volts. At the same time larger and larger units are being used for this service, until the distributing class of transformers must be made to include ratings of 200 k.v.a., which is quite a step from the 50 k.v.a. maximum of a few years ago.

The increased demand for transformers of the higher voltages has led to the development and standardization of designs which follow to a considerable extent the characteristics of distributing transformers of the lower voltage classes. The main requisites of transformers for distributing service are that they have a high electrical efficiency, be electrically and mechanically rugged, and be weatherproof. Particularly, their insulation strength and mechanical construction must be such that they can be put into service with the least trouble, and require practically no further attention. Such characteristics are especially demanded of the higher voltage transformers, as they are more often installed in out-of-the-way places, at relatively long distances from the central or substation. As shown in Fig. 1, the rectangular core type of construction is used, because it is particularly adapted to small, high-voltage transformers.

One of the main difficulties emphasized by the higher voltages is the necessity of keeping moisture out of the transformer case. While the windings, as shown in Fig. 1, are given the vacuum and impregnation treatment, which is the most effective way of preventing the absorption of moisture into the coils, moisture should not even be permitted to enter the case. The joints requiring special care to keep tight are between case and cover, and where the high voltage bushings enter the case. These must not only be weatherproof, that is, tight enough to prevent rain being driven in by the wind, but the casing must be practically air-tight, so as to prevent, as far as possible, the breathing action resulting from sudden changes in atmospheric temperature. Where damp air is drawn into the transformer and the moisture condensed on metallic parts, sufficient water may be accumulated in the course of time to cause trouble. Instead of using a felt gasket compressed between the case and cover with two bolts, as is found satisfactory with transformers of lower voltage, a woven asbestos gasket compressed with four equally spaced

bolts is used. This gasket is treated and impregnated so as to make it air-tight and at the same time soft and flexible.

The high-voltage bushing is composed of a large bell-shaped piece of porcelain projecting downward from the top of the transformer, as shown in Figs. 2, 3 and 4.

FIG. 1—WINDINGS OF 22 000 VOLT DISTRIBUTING TRANSFORMER

This construction, which is similar to that used by the lower voltage transformers, is weatherproof, as the rain naturally flows away from the opening in the tank. The surface of the porcelain bushing is smooth, to prevent the accumulation of solid matter from smoke, sand-storms or salt spray. The lead passing through the bushing is a treated cloth insulated conductor, cemented in place, the glazing being omitted from the inside of the bushing so that the cement will adhere to its surface. The thickness of the insulation on the conductor is prac-

FIG. 2

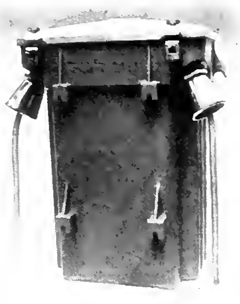

FIG. 3

FIGS. 2 AND 3—22 000 VOLT DISTRIBUTING TRANSFORMER WITH CAST-IRON CASE

tically 0.5 inch, composed of varnish treated cloth, with a covering of weatherproof braid, the total diameter over the braid being about 1.125 inches. To prevent syphoning of oil through these leads, the ends inside the case are taped over, as shown in Fig. 5, so as to keep oil from entering the lead. Even with oil having free access to the lead, the syphoning would be practically negligible, because of the gum which is used between the layers of the treated cloth. This gum fills the space between layers so as to leave no ducts through which oil could

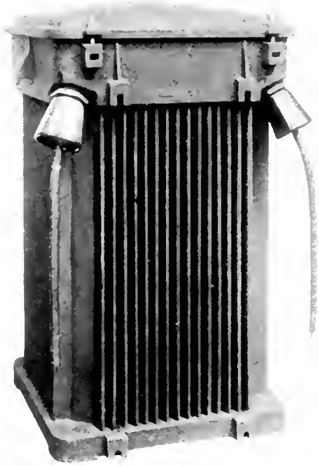

FIG. 4—22 000 VOLT DISTRIBUTING TRANSFORMER WITH PRESSED-STEEL CASE

be drawn. As shown in Fig. 5, the porcelain bushing is cemented into a standard pipe bushing. The glazing is omitted from the porcelain at the place where it passes through the pipe bushing, and the porcelain is also scored at this point, so that the cement may get a grip on its surface. The whole bushing with lead is screwed into the transformer case, the case having been tapped

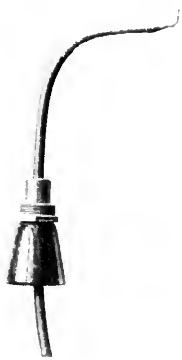

FIG. 5—HIGH-TENSION BUSHING

with a standard pipe thread. The entire bushing and lead can thus be taken out of the transformer for shipment and be easily put into place again when the transformer is installed, thus preventing breakage of bushings in shipment. The holes in the tank are closed during shipment with standard gas plugs.

The Engineering Evolution of Electrical Apparatus—XXIII

THE HISTORY OF THE LIGHTNING ARRESTER—(*Concl.*)

R. P. JACKSON

THE DISCOVERY of the non-arcing alloy marked a great advance in lightning protection and offered a way of producing arresters to meet the rapidly rising alternating voltages which appeared in the years 1900 to 1906. One of the first discoveries made in the application of this principle was that of the characteristics of the shunted gap. It is said that this discovery first came about through the effort to measure the voltage over a small arc controlled to a rough approximation of constant current by means of impedance. It was found that as soon as the voltmeter was put in parallel with the arc, the arc would drop out or disappear. This disclosed to the observer that it was difficult to maintain an alternating-current arc with a certain amount of resistance in parallel. Use was soon made of this fact to increase the arc-suppressing character of alternating-current lightning arresters.

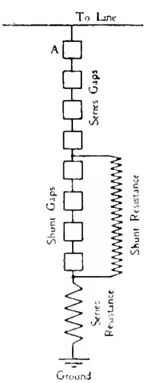

FIG. 14—ARRANGEMENT OF THE LOW-EQUIVALENT LIGHTNING ARRESTER FOR 0000 VOLT CIRCUITS

Practically, two sets of arrester gaps were put in series and one of them shunted by a resistance of suitable value, and if necessary to limit the power current another resistance was put in series with both sets of gaps. This lightning discharge would, if of any volume and of high frequency, pass over the unshunted or series gaps bringing the line potential directly to the shunted gaps. Here the discharge would divide and part go through the shunt resistance and part, usually the larger part, over these shunted gaps and to ground through the series resistance. The shunt resistance would draw off the power current from the shunt gaps, and when the arc in these gaps had disappeared the ohmic value of the shunt and series resistances together would limit the current to such a value that it could in turn be suppressed by the series gaps. The operation was then completed as the arrester had cleared itself.

It was found in connection with this combination that the voltage necessary to break down these series and shunt gaps initially was not appreciably greater than that required by the series gaps alone. There had been developed by Mr. Percy H. Thomas a method of comparing arresters by measuring the so-called "equivalent spark gap." The arrester above described had a high arc suppressing power and a low equivalent spark gap, and was for that reason named by Mr. Thomas the "low equivalent arrester." Its scheme of connections is shown in Fig. 14. The method of measuring the equivalent spark gap was to charge a condenser of a capacity of about 0.1 microfarad to a potential of 30 000 to 60 000 volts and then discharge this condenser over the arrester with a plain ball spark gap in parallel. For convenience, spheres of one-half inch diameter were used, and this distance between them, over which the discharge would pass as readily as over the arrester, was called the "equivalent spark gap." Fig. 15 shows the scheme of charging and discharging such a condenser from an alternating-current power circuit.

This low equivalent arrester began its development at 2200 volts and continued with the rise of alternating voltages to 88 000 volts. A great many were made for 33 000 volts, a rather limited number for 66 000, and only one power company was equipped with 88 000 volt low equivalent arresters. That seemed to be about as high as that type of arrester could be carried. Even

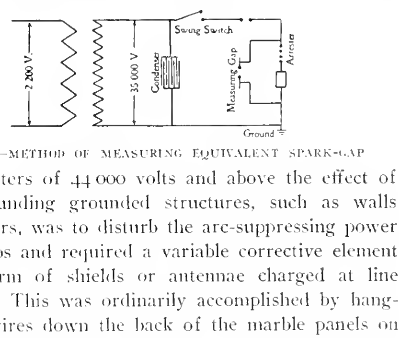

FIG. 15—METHOD OF MEASURING EQUIVALENT SPARK-GAP

with arresters of 44 000 volts and above the effect of the surrounding grounded structures, such as walls and barriers, was to disturb the arc-suppressing power of the gaps and required a variable corrective element in the form of shields or antennae charged at line potential. This was ordinarily accomplished by hanging live wires down the back of the marble panels on which the gaps were mounted and encasing such wires in insulating tubes.

Low equivalent arresters or devices of similar multi-gap character are to be found in all parts of America, and they have served to afford a considerable degree of protection against lightning, as well as to an element of interest to station operators as to what might have happened to their apparatus if the discharges seen to pass over the arresters had gone into such apparatus.

During the period just before and after 1900 Mr. Thomas developed the scheme of protecting inductive apparatus by means of a combination of a choke coil and a condenser. This combination was called the "static interrupter." While it was not manufactured long, due to cost reasons, yet its theory was essentially correct.

Electrically considered, any apparatus having windings on iron has inertia and is fragile. The changing of

its magnetic condition is similar to the accelerating of a mass of fragile material, like a structure of glass or porcelain. Such change can take place at certain speeds in entire safety, but a sudden blow is dangerous. That is why lightning is dangerous to transformers and generators, etc. If instead of striking the blow on the

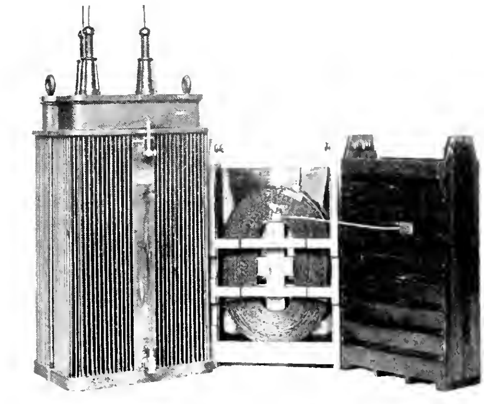

FIG. 16—EARLY STATIC INTERRUPTER

glass or porcelain, above referred to, it is struck against a mass of metal with a sheet of rubber interposed between such mass and the glass or porcelain, it is obvious the destructive effect of the blow will be much lessened. Mr. Thomas conceived the idea of interposing a choke coil and a condenser as the electrical equivalent of the mass of metal and the sheet of rubber. Such a device is shown in Fig. 16. A considerable number were produced between 1900 and 1905, and were really excellent in protective character. The expense of the large high-voltage, oil-insulated condenser gradually compelled its omission, leaving only the oil-insulated choke coil, which continued for some years longer, when it also went out of style for similar reasons of cost. The static interrupter is theoretically a very effective device, and if a way is ever found of producing cheap, high-voltage condensers its revival might be warranted.

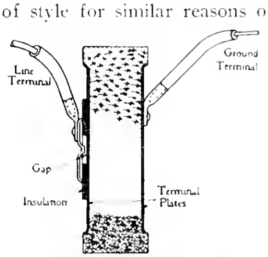

FIG. 17—CROSS SECTION OF ARRESTER SHOWN IN FIG. 18 INDICATING DIRECTION OF CURRENT FLOW DURING DISCHARGE

In the 500 volt direct-current field the tank type of station arrester continued in use for a number of years, but its manufacture finally ceased about 1908. For line service there came into use between 1902 and 1904 a novel arrester known as the "MP," an abbreviation for "multipath." This device is extensively used and consists of a block of granular material with metal plate terminals of some area on each side. Part of the material of the block is conducting granules, and these are kept slightly separated by an insulating filler and binder. The result is that a lightning discharge divides into myriads of multi-branches instead of following a single path through the block. Fig. 17 shows, in a way, how this occurs, and Fig. 18 shows how this device was worked out in commercial forms. This multipath

FIG. 18—600 VOLT MULTIPATH RAILWAY ARRESTER

scheme was brought out by Mr. Thomas, and further developed by Mr. N. J. Neall, and has had about the longest active commercial life of any of the arrester devices. Considering its simplicity it was a happy idea.

Several efforts were made to use the same principles by using several blocks in series for higher voltages without success. When so used there was a strong tendency for the power current to follow the lightning discharge and melt a hole through the whole series. Various combinations of a gap in series with a resistance and either a mechanical or a magnetic circuit open-

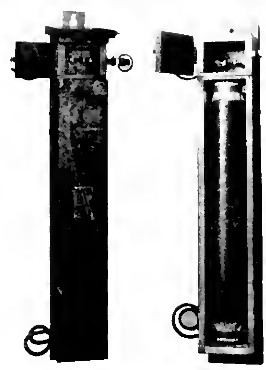

FIG. 19—CONDENSER TYPE ARRESTER FOR CAR MOUNTING

ing scheme used to suppress the power arc were extensively used at various times. The heavier power circuits with direct-current voltages of 750 have made life hazardous to many of the older types of direct-current

railway arresters, and the more recent use of direct-current potentials up to 5000 volts renders the arrester problem for lines and cars so equipped still more difficult. The modern tendency is to return to the static interrupter idea by the use of condensers with a gap in series and this condenser kept discharged by means of a very high resistance in parallel with it. Arresters of this type are shown in Fig. 19. Improved methods of producing condensers will probably extend the development of this type of arrester, especially for direct-current work.

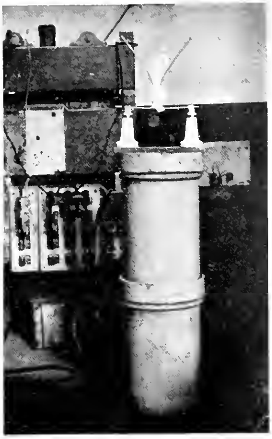

FIG. 20—EARLY EXPERIMENTAL ELECTROLYTIC LIGHTNING ARRESTER

The most notable development in lightning protection in recent years has been that of the electrolytic or aluminum cell arrester for both alternating and direct-current circuits. This work was begun at East Pittsburgh early in 1906, and was carried on for the next three or four years and developed to the present commercial forms. Curiously enough, a similar line of work was started at Schenectady, N. Y., at about the same time, and for some months neither group of engineers knew of the others' work.

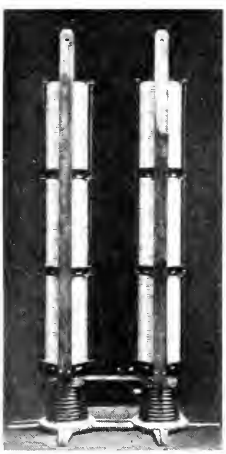

FIG. 21 — MODERN HIGH-TENSION ELECTROLYTIC LIGHTNING ARRESTER TRAY STRUCTURE

The peculiar characteristics of aluminum which causes it to form a film in certain electrolytes of such exceeding thinness as to give a capacity of unusual value for the area involved, and also to give a safety valve action not otherwise obtainable, gives this material a peculiar value for purposes of lightning protection. This principle has been known for many years, and in itself involved no novelty. The problem was to adapt the unit of a single plate which would withstand a potential of about 420 volts to series combinations suitable for the voltages (up to 60 000) then in use. While various efforts were made with vertical plates in a jar, it was found impractical to combine sufficient units for more than 500 volt work. The first really successful experiment took the form of a sewer pipe stacked full of aluminum "pie tins" separated about one-quarter of an inch by means of insulating spacers. Each tray or pie tin was filled with electrolyte after having been properly treated in an electrolytic bath. By this means a unit suitable for about 10 000 volts was obtained. The writer has some of these original pie trays at home that are still in domestic service.

The commercial development at first followed this lead and took the form of stacks or columns of aluminum cones or trays mounted in stoneware jars, as shown in Fig. 20. While this design eliminated the problem of an insulated terminal for the line side of the arrester column, yet the irregularity of stoneware construction and its tendency to fracture afterwards necessitated steel tanks and outlet bushings, as shown in Fig. 22.

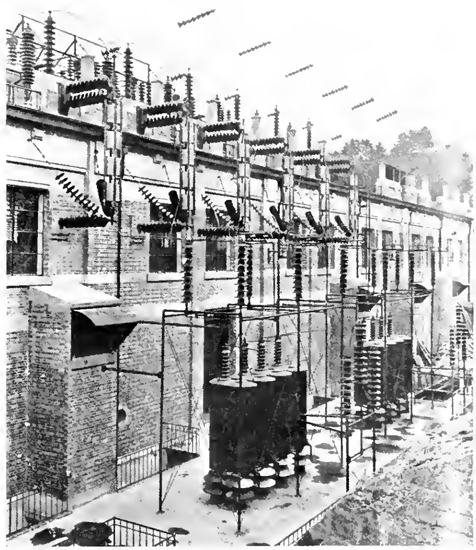

FIG. 22—TYPICAL INSTALLATION OF 115 000 VOLT, THREE-PHASE UNGROUNDED NEUTRAL ELECTROLYTIC LIGHTNING ARRESTERS

At the plant of the Inawashiro Hydroelectric Company, Japan.

The more recent years have brought many variations of the principles herein described to meet commercial requirements, and numerous curious schemes, in many cases quite effective, have been tried out by operating engineers. Lightning still continues, however, and occasionally does damage. The increased factor of insulation made possible by a higher development of the art has rendered the responsibility of lightning protective apparatus materially less as to the danger of an actual injury occurring to the power apparatus. The increased size and power capacity of such apparatus has, on the other hand, increased the importance of protecting it.

Protection of Distributing Transformers from Lightning

Q. A. Brackett

ELECTRIC distribution circuits for light and power, at voltages from 2200 to 6600, afford one of the most widespread fields for the application of lightning-protective apparatus. As in the case of electric railways, the number of separate pieces of apparatus requiring protection is quite low. The public, however, is demanding uninterrupted service, and lighting companies are finding it more and more necessary to prevent interruptions due to failure of transformers. There is a growing tendency, therefore, not only to demand better lightning arresters and transformers, but also to increase the number of arresters used, even to the extent of having an arrester for every transformer.

This makes the question of the type of lightning arrester of still greater importance. If it is to give satisfaction, the arrester must be designed to have certain definite qualities and characteristics suited to this service. First, it must be low in cost, in order that the investment for protection may not be large in proportion to the value of the apparatus to be protected, especially where so many separate units are involved. Second, it must be reliable and free from operating troubles. It must be able to handle all ordinary discharges without serious injury to itself and without grounding the line. Third, it must afford the maximum protection to the transformer against lightning that is compatible with low cost and reliability. No arrester can be expected to give absolutely perfect protection, because the results in any case are largely affected by the condition of the particular installation. A good arrester, improperly installed, cannot be expected to give the best results. Fourth, the arrester must be so designed that inspection and repairs are easily and safely made. With an increase in the number of arresters used, the chances of injury to linemen increase greatly and, not only from the general standpoint of humanity, but also in view of the spread of employers' liability laws, it is of great importance that this danger be minimized. There is no good reason why the "safety first" idea should not be applied to lightning arresters as well as to other apparatus.

A new 2200 volt outdoor arrester is shown in Fig. 1 in which the "safety first" principle has been embodied in addition to the other desirable characteristics. This arrester consists of three series spark gaps between knurled non-arcing metal cylinders in series with a 100 ohm non-inductive resistance rod. These parts are mounted in a straight line on a porcelain base and enclosed in a weather-proof cast-iron case. Both the line and ground leads are insulated from the box by porcelain bushings. This combination of non-arcing gaps and a resistance has been used in 2200 volt arresters of earlier design for years, and long experience has shown that it gives excellent service.

The operation of the arrester depends upon the fact that the non-arcing metal gaps have the property of suppressing the power arc which follows a lightning discharge at the end of the first half cycle. This well-known principle allows the use of much smaller resistance rods, without undue heating, than could be used, for instance, with a horn gap arrester, which allows the arc to persist for many cycles before it can rise high enough to break. This allows the arrester to be kept small and compact and also reduces its cost. The number of gaps is the lowest that can be relied upon to break the arc following a discharge, while the resistance is lower than that used in many other arresters for this service and as low as experience has shown is advisable.

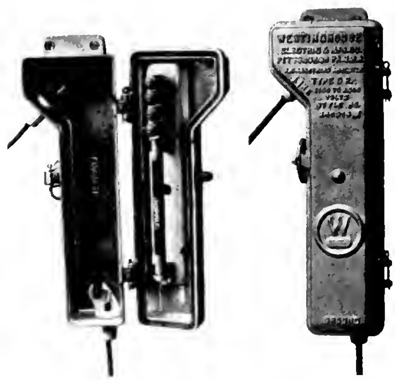

FIG. 1—A NEW 2200 VOLT, OUTDOOR, ALTERNATING-CURRENT LIGHTNING ARRESTER

Showing box opened and closed.

The small spark gap means a low discharge voltage, which insures that the arrester will start to give protection before the voltage of a surge has risen to a harmful value, while the low resistance in series provides a very free escape for the lightning. Arresters of this description have been available before, but the new "safety first" feature has just been introduced. This consists in mounting the porcelain base, which carries the spark gaps and resistance rod, on the inside of the cover of the arrester box, while the line and ground leads are brought

in through bushings to terminal studs in the bottom half of the box. Connections between the arrester element and the terminal studs are made by flat springs, which make contact only when the box is closed. When the box is opened these connections are broken and the arrester element, being mounted on the cover, is carried to such a distance from the line terminal that it can be safely handled by the lineman. The cylinders can be turned around to present fresh surface for discharge if they show signs of burning, the resistance rod can be replaced if necessary, or the entire arrester element can be removed and a new one substituted without danger to the lineman and without disconnecting the arrester from the line or removing it from the pole.

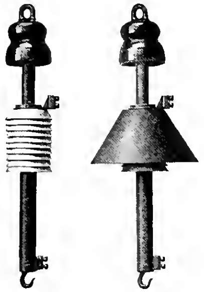

FIG. 2—INDOOR AND OUTDOOR, NON-ARCING METAL LIGHTNING ARRESTER
For 6600 volt circuit.

The arrester is arranged to be mounted vertically downward from the crossarm and a lug is provided at its top for that purpose, with holes for standard three-eighths inch lag screws. This arrangement takes up a minimum of space on the crossarm. Both terminal bushings are arranged to shed rain effectively, while flax packing insures a water-tight joint around the cover, which is hinged and fastened by a spring latch.

A 6600 volt arrester in which these same results have been accomplished in a different way is shown in Fig. 2. It is also of the non-arcing metal type, but the spark gaps are formed between concentric bell-shaped electrodes instead of between cylinders. A large sparking surface is thus provided without readjustment, and nine spark gaps are used in series with a resistance rod of 400 ohms. The spark gap bells are mounted on a central insulated steel rod, which at its upper end is cemented into a porcelain insulator. The lower end of the steel rod carries a bakelite micarta tube, which encloses the resistance rod; the insulation of the spark gaps is also of bakelized micarta. This type of arrester is arranged to hang from the line wire at a sufficent distance from the pole to be out of the way of the lineman. This contributes to safety first but, where preferred, the arrester can be hung from the crossarm.

This arrester is provided with a metal rain shield to protect the spark gaps from rain and snow. Another feature is the static effect of the steel rod through the center of the spark gap bells. As this rod is at ground potential it greatly increases the capacity current through the upper gaps, considered as small condensers. This causes the voltage across the gaps to divide unequally between the gaps and pile up across the upper gaps, thus lowering the break-down voltage of the arrester. The breaking of the power arc following a discharge is greatly helped by the cooling of the gaps due to their large area and open exposure to the air, which also prevents the accumulation of the metallic fumes following discharges that cause so much trouble in lightning arresters where the spark gaps are confined in a very small space.

In Fig. 3 is shown a non-arcing metal type of lightning arrester for outdoor service on 11 000 and 13 200 volt circuits. This arrester is of a more elaborate design than those previously described and makes use of a shunt as well as a series resistance. Light discharges pass through a few gaps and the two resistances in series, while heavy discharges leave the shunt resistance and by-pass through the shunt gaps, so that only the series resistance limits the freedom of discharge. When lightning has passed, the non-arcing shunt gaps return the power arc to the shunt resistance, which, added to the series resistance, lowers the current to a value that the series gaps can interrupt. Outdoor arresters of this type and for this voltage have only recently been available, but arresters for as high as 22 000, or even 33 000 volts, can now be made. The resistances used are of the rod type and are mounted directly on the spark gap units. They are an improvement over the wire resistances formerly used; the material employed in the rods is permanent in its resistance value and is practically unaffected by static.

Adequate protection from high voltages is now available for all classes of distributing transformers, and the experience of many operating companies is showing the advantage to be gained by a more complete system of

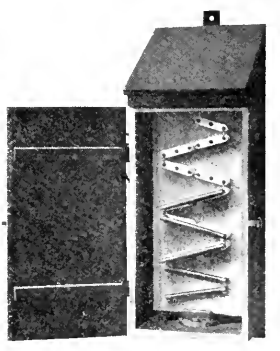

FIG. 3—A LOW-EQUIVALENT, NON-ARCING TYPE OF LIGHTNING ARRESTER
For 11 000 and 13 200 volt circuits.

protection than has been common in the past. Lightning arresters are now available that will not only provide adequate protection, but will also allow that ease and safety of installation and inspection that becomes of increasing importance as the number of installed units increases.

The Electrical Equipment of the New William Penn Hotel

J. Irvin Alexander
Contract Dept.,
Duquesne Light Company, Pittsburgh

IN THEIR decision to have the William Penn Hotel, which was opened in Pittsburgh on March 9th, 1916, entirely modern in every respect, the management planned a most elaborate and extensive electrical equipment to provide for the utmost service and comfort to its guests. From the huge electric sign towering above the top of the building to the electrically-driven sump pump located below the sub-basement floor, the hotel is completely electrified. Eliminate the silent and efficient servant—electricity—and the William Penn Hotel as it stands today would be utterly impossible.

A careful study was made of the relative merits of central station and isolated plant service, giving due consideration to reliability of operation and the many other advantages of central station service, as well as the tremendous amounts of both high and low-pressure steam which are required for the daily normal operation of a big modern hotel, even during warm weather. The decision was finally made to purchase all the electric service from the Duquesne Light Company and the steam from the Allegheny County Steam Heating Company.

FIG. 1—THE WILLIAM PENN HOTEL

Rising twenty stories above ground, penetrating three stories underground and covering the better part of an entire city block, the William Penn Hotel, erected at a cost of over $6 000 000, is furnished with a lavishness for comfort and luxury which places it among the leading hotels of the country. Its one thousand guest rooms, spacious halls, corridors, cafes, restaurants and reading rooms are all equipped in the most modern manner to provide for the comfort, convenience and pleasure of over 1500 guests.

The furnishings of the main lobby, shown in Fig. 2, may be considered as typical of the entire hotel. Like the exterior of the building, it is patterned after the style of the Italian Renaissance, and is without columns to break the vista or to interfere with the free movement of the guests. The woodwork is of dark walnut and the furnishings are dull, subdued and massive. The ceiling is of two-story height, and a balcony parlor overlooks the entire room. At the rear are the executive quarters, news stands, etc., and the elevators.

At either side of the lobby are the main restaurants. The one at the left, shown in Fig. 3, is finished like the lobby, with walnut and green marble, and subdued colorings for the ceiling and walls, broken only by an elaborate mural decoration representing "The Seasons" in a series of harvest festivals with life-size figures. The other restaurant is of equal size and similar appointments, being finished after the Georgian period, in ivory and gold. A third restaurant, on the basement floor, is finished after the Elizabethan period.

One of the most spectacular rooms of the building is the combined ballroom and banquet hall, which occupies one-third of the floor space on the eighteenth floor, with a balcony around the entire room. This room has seating capacity for 900 diners, and more can be accommodated in the gallery if necessary. It is decorated somewhat after the delicate color scheme of the Georgian period restaurant, although elaborateness of detail is more pronounced. A special feature of this room is the disappearing stage, which can be elevated or left at floor level, as desired. Adjoining the banquet hall are numerous smaller dining-rooms for private parties, with capacities for 10 to 160 guests. There is also in the hotel a complete cafeteria, operated exclusively for the help.

Separate kitchens are provided for the main restaurants, the Elizabethan room and the banquet hall, each equipped completely with ranges, tables, ovens, steam heaters and many electrically-operated devices which hasten or improve the preparation of the food. Above the main kitchen, small service kitchens branch out on every third floor all the way up to the big kitchen serving the banquet hall, each service room

being prepared for complete serving of meals to guests in their apartments and all being connected together by dumbwaiters.

The guest rooms are furnished in a sumptuous manner, and range in price from $2.50 to $28 per day, exclusive of the "state suite" for special occasions, which rents for $50 per day. The size and location of the room determine its value, the equipment and furnishings being much the same in general character. The complete service will require over 800 employees, over 100 of them being in the kitchens, and 130 being regular waiters and service men.

ELECTRIC POWER CONSUMPTION

The total connected load of the William Penn Hotel includes approximately 1000 horse-power of direct-current motors at 220 volts and 800 kilowatts of lighting and miscellaneous small power motors on the lighting circuits at 110-220 volts, three-wire, single-phase, alternating current. The building contains over 20 000 Mazda lamps, ranging in size from 10 to 250 watts. The five-minute maximum demand under normal operating conditions is approximately 600 kilowatts for lighting and 560 kilowatts for power, the maximum coincident demand for light and power being approximately 1000 kw. Based on readings taken during the first two months of operation, it is expected that the annual current consumption for power will run approximately 2 700 000 kilowatt-hours and for lighting approximately 900 000 kilowatt-hours.

As the Duquesne Light Company needed a substation in the immediate vicinity of the hotel both for the hotel load and for the load of several other large office buildings which are being erected in the near neighborhood, they, in conjunction with the Allegheny County Steam Heating Company, contracted with the hotel management for sub-basement floor space for a substation adequate for their needs. At present there are installed in this substation three 200 kw motor-generator sets, converting three-phase, 2200 volt power to 220-110 volts, three-wire, direct current; three 250 kw, single-phase transformers for reducing the line voltages from 11 000 volts to 2200 volts for the motor-generator sets, and three 250 kw, 11 000 to 110-220 volts, three-wire, single-phase transformers for supplying the lighting load; also a switchboard and switching equipment for controlling the high-tension incoming lines, as well as the transformer secondaries and the output of the motor-generators. Due to the cramped condition of the room, it was found necessary to install this switching equipment in a high, narrow form, one bus with its oil circuit breakers being installed on the first floor level, the second bus with its oil circuit breakers on the second floor level, and the control panels with the instruments, relays, etc., on the third floor level, which is about three feet below the regular operating gallery of the substation. The bus-bar and switch structures are built of concrete and asbestos lumber, and the whole structure is designed to give the maximum possible reliability. The floor level of the substation and boiler room is approximately 60 feet below the adjacent sidewalk level of Sixth avenue. All this electrical equipment as at present installed is to take care of the hotel load, except the switching equipment, which is installed for an ultimate station capacity of 10 000 kw. Ample room is provided for additional transformers and converting apparatus, which it is expected will be installed in the near future. There is also installed in this substation a battery of four 600 hp boilers with furnaces equipped for burning gas normally, but also arranged so that coal can be burned in case of emergency. Only one of these is at present being operated on the hotel load.

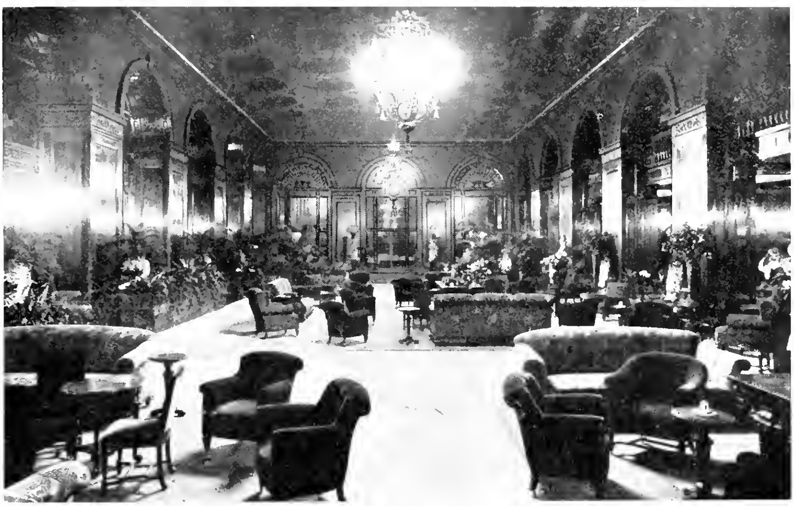

FIG. 2—GENERAL VIEW OF MAIN LOBBY

LIGHTING EQUIPMENT

The elaborate and lavish use of artificial lighting is as essential a part of a large hotel as are its restaurants. Perhaps the most spectacular lighting features are those of the ballroom and lobby. The lobby, which is said to be the largest in the country, has a two-story ceiling and its architectural features are massive in effect and dark in tone. Two huge chandeliers were designed especially to harmonize with the general architectural features and furnish the general illumination, while semi-indirect fixtures under the balcony, sidewall brackets and special pedestal and table lamps add brightness to the general effect and prevent dark shadows. All the lamps which are not covered are completely frosted. The lighting of the restaurants is similar in general design, big ornamental chandeliers furnishing the general illumination and sidewall brackets obviating shadows near the walls. The lighting fixtures in the ballroom are designed especially to make silks shimmer and jewels scintillate, and the chandeliers are a mass of cut glass prisms and sparkling lights, while dainty sidewall candelabras under the balcony add to the general brilliancy.

FIG. 3—THE ITALIAN RESTAURANT

In keeping with the general tone of the hotel the lighting of the individual rooms has been most elaborately carried out. In addition to the usual fixtures in the center of the room, individual lamps are located on each side of the dressing tables, a reading lamp is provided at the head of the bed and wall plugs are provided for the connection of special table lamps or electric fans, electric irons, curling iron heaters or other conveniences. The corridors are kept adequately lighted at all times with semi-indirect fixtures. A special circuit is run from the switchboard to the fire exit lights and the lights in the enclosed fire escapes, and these lights are kept burning at all times, no switches for turning them off having been provided.

Electric Sign—On the roof at the north side of the building, facing the Pennsylvania Railroad Station, the name of the hotel is spread out in old English letters. The total length of the sign is 140 feet, the capital letters being 18 feet in height and the small letters 12 feet in height. The sign is designed so as to be equally legible by day and by night. Fifteen hundred 25 watt, 110 volt tungsten lamps are required for its illumination, giving a total connected load of 37.5 kilowatts. The letters are of channel construction and are mounted on an angle iron frame work.

REFRIGERATION

All refrigeration in a modern hotel is done either by direct expansion of ammonia or by the use of cold brine which has been chilled by the expansion of the ammonia, the latter being more satisfactory except where extremely low temperatures are desired. To secure the best results, the various edibles must be maintained at different temperatures. For instance, vegetables must not be frozen, but must be maintained at a fairly low temperature, approximately 40 degrees F. The same statement applies to butter, milk and fresh eggs. Game must be kept at as low a temperature as possible without freezing, usually at about 35 degrees F., while fresh meats are kept better at a temperature of 38 to 40 degrees. Sea foods, on the other hand, such as fish, lobsters, etc., must be frozen and are kept at a temperature of about 25 degrees F. Ice cream must be stored at a temperature below freezing. All of these foods must be maintained in large quantities in the main storerooms and in smaller quantities in each of the kitchens. For this reason, in the William Penn Hotel, 62 different refrigerators are maintained, each at its proper temperature, in addition to the ice cream freezers and ice and ice cream storage. No cooling is done by direct expansion of the ammonia, except the drinking water, all the rest of the cooling being done by brine, which is chilled by the expansion of the ammonia from two large compressors, each driven by a 90 hp, 225-450 r.p.m. adjustable speed motor, each compressor having a capacity equivalent to 50 tons of ice per day. Three separate brine-circulating systems are provided, one, known as the low-pressure system, caring for the requirements of the hotel below the fifth floor (35 refrigerators), at a temperature of 10 degrees F., being circulated by a duplicate equipment of centrifugal pumps driven by 7.5 hp, 1100-2200 r.p.m. motors; a second, known as the high-pressure system, caring for the requirements above the fifth floor (27 refrigerators), at the same temperature, being circulated by duplicate reciprocating pumps

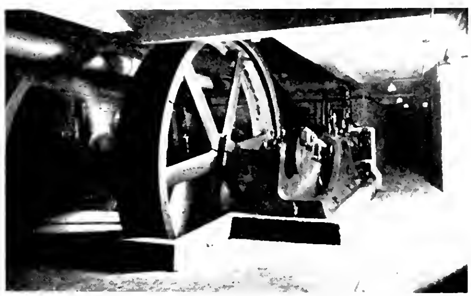

FIG. 4—THE TWO AMMONIA COMPRESSORS FOR THE REFRIGERATING PLANT

driven by 1.5 hp, 900-1800 r.p.m. motors; and the ice cream brine, at zero F., which is circulated by duplicate reciprocating pumps, driven by 1.5 hp, 900-1800 r.p.m. motors.

Ice Water—Specially filtered and chilled drinking water service is provided in each of the guest rooms and at intervals throughout the corridors and lobby. This cold water is continuously in circulation through a return pipe system so that it has no opportunity to become warm from standing in the pipes. It is chilled by the direct expansion of ammonia in the basement and is circulated by duplicate centrifugal pumps, driven by 7.5 hp, 1100-2200 r.p.m. motors.

Ice Manufacture—Although no refrigeration is done directly by ice, approximately 9000 pounds of ice (30 cakes) are required per day to supply the cracked ice for drinking water, butter plates, relishes, etc., for the table and for the cracked ice for the bar. This ice is manufactured in the basement of the hotel in a special freezing room having 100 standard 300 lb. tanks, and a capacity of 50 cakes per day if necessary, using the raw water ice system. A brine agitator driven by a 3.5 hp motor circulates the brine among the tanks. The water in the tanks is agitated by compressed air, until the cake is nearly frozen, when the remaining water is replaced with distilled water, and the cake frozen solid. An ice storage room lies adjacent to the freezing room. The ice is crushed for table use in a motor-driven ice crusher or sawed into two-inch cubes by a motor-driven gang of circular saws.

PUMPING EQUIPMENT

To ensure absolute reliability of water supply a complete dual system of pumping equipment is provided, with the idea that should one system fail, the other could take its place. All the water used is supplied by the

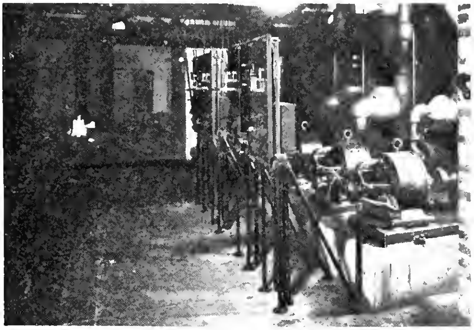

FIG. 5—GROUP OF MOTOR-DRIVEN CENTRIFUGAL PUMPS

For circulating brine through the low-pressure system and for circulating the drinking water. Additional brine circulating pumps are shown in the left background.

city, and filtered by equipment in the hotel; the drinking water is then filtered for a second time before passing into the drinking water mains. On account of the height of the building the city water pressure (about 80 pounds per square inch) is not depended on for service above the fifth floor. Instead, for the higher floors, the water is pumped into large metal tanks on the nineteenth floor, the pumps being regulated automatically to maintain the level in the tanks. Two centrifugal pumps of 350 gallons per minute capacity against a head of 317 feet are provided for this purpose, and are driven by 50 hp motors at 1700 r.p.m. This is known as the high-pressure system, as distinguished from the low-pressure system supplying water below the fifth floor. In addition, a centrifugal pump of 200 gallons per minute capacity against a head of 33 feet, driven by a 10 hp, 1970 r.p.m. motor, is available to maintain the pressure in the low-pressure system if the city water pressure should ever become so low as to need boosting. One of the high-pressure house pumps is also arranged so that it can be used on the low-pressure system in case of emergency.

FIG. 6—THE HIGH-PRESSURE HOUSE PUMPS AND FIRE PUMPS

The warm water from the ammonia condensers is collected in tanks on the engine-room floor, and is thence pumped into the high-pressure hot water system. Ordinarily more hot water is used than is supplied by the condensers and the deficit is then supplied from the city mains. If the condenser water is not all used it overflows into a sump and with other waste water is pumped out into the sewers by a vertical shaft, immersed centrifugal pump, driven by a 20 hp, 650 r.p.m. vertical motor, with automatic float control. The hot water is heated to about 180 degrees F. by steam coils in duplicate for both high and low-pressure systems, and is circulated through a return pipe system at each pressure by duplicate centrifugal pumps driven by 5 hp, 1100 r.p.m. motors, four pumps being required for this service.

The two fire pumps are also of the centrifugal type. They are capable of delivering 500 gallons per minute against a pressure of 100 pounds. Each pump is driven by a 75 hp, 1700 r.p.m. motor, and provided with an automatic bell and light alarm for both high and low water. The water is pumped up to a 50 000 gallon tank just under the roof and distributed from there to the fire plugs by gravity.

AIR COMPRESSORS

Two large air compressors, each belted to a 25-35 hp, 350-700 r.p.m. motor, furnish air at about 30 pounds pressure for all pneumatic tubes, the bar, barber shop and numerous other similar applications and for the

pneumatic injectors which are used to raise the sewage from that part of the building which is below the city sewers. The compressors are controlled automatically so that an even pressure is maintained at all times.

ELEVATORS

The elevator and dumb waiter equipment comprises eleven elevators, seven dumb waiters and one stage lift.

FIG. 7—ONE OF THE AIR COMPRESSORS

The hot water heaters are located in the balcony and the hot water circulating pumps under the balcony, as shown in the background. The controllers throughout the entire installation are mounted immediately adjacent to the motors, as shown above.

The six passenger elevators and two service elevators are of the 1 : 1 gearless traction type and are driven by 39 hp, 58 r.p.m., 240 volt, direct-current motors. The controllers have full magnet regulation throughout and govern the speed by the series-parallel method. They are protected with all safety relays, such as overload, low voltage, etc. These elevators have a capacity of 2500 pounds at a speed of 550 to 600 feet per minute, and will lift a maximum load of 3000 pounds.

The 2 : 1 traction freight elevator is similar to the passenger elevators except for the reduction in speed

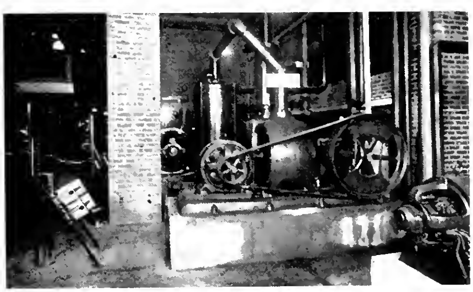

FIG. 8—THE VACUUM PUMP AND CONTROL PANEL

and increase in load obtained by means of the rope gearings on the car and counterweight. A 43 hp, 135 r.p.m. motor is used to operate this elevator, which has a duty of 3300 pounds at 450 feet per minute, and will lift a maximum load of 4000 pounds. There are also two drum freight elevators of the usual worm-geared type, which are driven by 40 hp, 800 r.p.m. motors having a duty of 3300 pounds at 350 feet per minute.

Each of the elevators is operated by means of a master switch in the car and all apparatus in connection with the elevator equipment is of the very latest and most approved design. Variations in speed of the elevator cars are governed by means of relays and centrifugal governors. The contacts on the governor are opened in case the car speed should become excessive, which interrupts the circuit to the potential switch (circuit breaker), thereby automatically bringing the car to rest. The governor has a further function of applying the mechanical safeties which grip the guide rails in case of further excessive speed of the elevator car. Automatic and limit stops are provided at the top and bottom of the hatchway, bringing the car to rest independently of the operator.

The efficiency of all the equipment furnished is the highest known to the art, compatible with long life and low upkeep. The power consumption and operating costs are thereby kept to minimum amount. Added

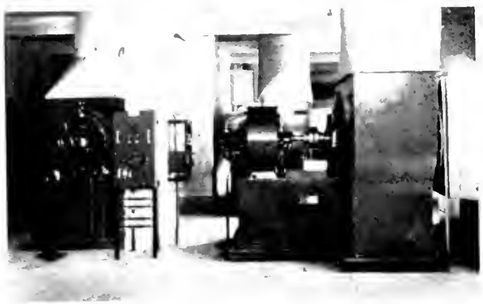

FIG. 9—TWO OF THE EXHAUST FANS AND CONTROLLERS

safety features are procured with this class of equipment by the use of six hoisting ropes on each elevator car and the installation of automatic oil buffers, which, in case of over-travel from any cause will bring the car to rest from full speed without injury to the passengers.

A unique feature is the stage lift in the ballroom. The stage is supported on four vertical screws geared to an electrically-driven mechanism and, by means of automatic push-button control, it can be raised about three feet above the floor level. The stage itself weighs approximately 20 000 pounds and, in addition to this, a load of 4000 pounds can be lifted three feet in one minute, a very unusual duty as compared with ordinary elevator requirements.

The electric dumbwaiters, upon which the service of the hotel so largely depends, have a capacity of 200 pounds at 300 feet per minute, and can be despatched by automatic push-button control to any floor, thus giving accurate and rapid service. Other important features, which received the closest attention in making this elevator and dumbwaiter installation, were the procuring of quietness and smoothness of operation and the fire-

proofing of the doors and all other woodwork adjacent to the elevator hatchways.

VACUUM CLEANING

It may be taken almost for granted that a modern hotel will have a complete vacuum cleaning establishment. In the William Penn Hotel outlets are provided in every room or suite and at short distances in the corridors, dining-rooms and other large rooms. Ten inches of vacuum are maintained throughout this vacuum system by means of a reciprocating vacuum pump driven by 10 hp, 600 r.p.m. motor.

STEAM REQUIREMENTS

Steam is required in a hotel for general heating purposes, for heating water, for cooking, etc.

Heating—A hotel differs from almost any other large building in that the building itself is heated for 24 hours per day for seven and one-half to eight months during the year. In the William Penn Hotel it is estimated that 48 000 000 pounds of steam at low pressure will be required per annum for heating purposes. A vacuum of six inches is maintained on the return by duplicate rotary pumps, each driven by a 7.5 hp, 850 r.p.m. motor.

FIG. 10—THE BLOWER FOR VENTILATION OF THE BALLROOM
The centrifugal pump for the spray washing system is belted to the same motor. The washers are immediately back of the blower.

Hot Water—Tremendous quantities of hot water are used in any hotel for toilet purposes, scrubbing, cleaning, dishwashing, etc. In the William Penn Hotel it is estimated that 15 000 000 pounds of live steam will be required per annum for this purpose, based upon the figures obtained from actual operating conditions in other large hotels and from the actual steam consumption of the William Penn Hotel during the first two months of its operation.

Cooking—Live steam is used for a large part of the cooking at a pressure of approximately 60 pounds per square inch. It is estimated that over 12 000 000 pounds of live steam will be required per annum for this purpose.

Laundry—The William Penn Hotel is unique among large hotels in that it does not have a laundry. This is because it is owned and managed jointly with the Fort Pitt Hotel, which has a completely equipped laundry building which is operated independently from the hotel.

Total Steam—The above figures indicate that a total of approximately 75 000 000 pounds of steam will be required by the hotel per annum. All of this steam is purchased from the Allegheny County Steam Heating Company.

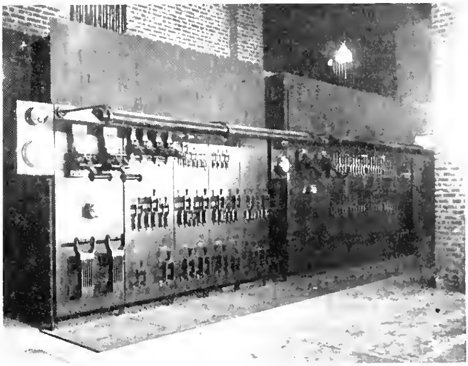

FIG. 11—MAIN SWITCHBOARD
Direct-current power board at left; alternating-current lighting board at right.

VENTILATION

Blowers driven by adjustable-speed motors provide exhaust ventilation for the kitchens, dining-rooms, lobby and basement, a total of 28 blowers, fans and exhausters being employed, which are operated by direct-connected, 2 : 1 ratio, adjustable-speed, shunt motors, varying from 5 to 50 horse-power in capacity. Most of these exhaust fans are located on the top floor and exhaust to the open air through the roof. Each blower equipment is calculated to handle the usual amount of ventilation at its normal speed, and unusual conditions can be taken care of by the 100 percent increase in speed adjustment which is possible. In addition to the exhaust fans, pressure blowers are provided to force fresh air into the ballroom and certain other parts of the building. The object here is not only to exhaust the vitiated air, as is the case in the kitchens, dining-rooms, etc., but also to provide a plentiful supply of freshly tempered and cleansed air. This air is first passed through spray

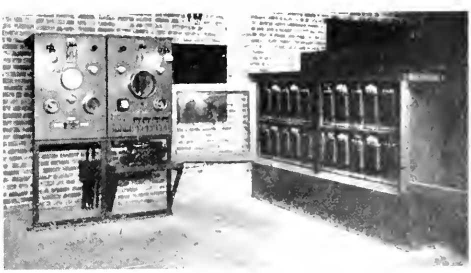

FIG. 12—SWITCHBOARD AND STORAGE BATTERIES
For the clocks and other low-voltage equipment

washers, which entirely remove all dust and soot, and at the same time considerably cool it for warm weather use. Steam heating coils are also installed in the air washers to warm the air in cold weather.

MISCELLANEOUS

In addition to the main motors which have been mentioned, numerous smaller ones are in use throughout the entire building. The kitchens especially are provided with motor-driven automatic dishwashers, potato peelers, meat and vegetable choppers, meat grinders, cream separators, egg beaters, coffee mills, emery wheels, buffing wheels, ice cream freezers, etc. A stock of over 100 portable fans is kept for use in the offices, dining-rooms and guest rooms during the summer months.

One of the interesting features of this hotel consists in the many supplementary uses of electricity. When a guest first registers this fact is announced to the various clerks, to all the dining-rooms, to the telephone information operator, and to many other departments simultaneously by means of an elaborate telautograph system. The time of arrival of telegrams or other messages is registered by electrically-operated time clocks. An electric clock in each guest room and wall clocks at frequent intervals throughout the corridors, lobby and other parts of the building are all controlled from two master clocks.

The complete intercommunicating telephone system is of itself of no small interest. The 1100 telephones in the building are connected to a nine position private switchboard having 75 trunk lines to the local Grant exchange, the telephones and board being adequate to serve a city of 15 000 people.

To provide current for all these miscellaneous uses of low-voltage electricity, duplicate motor-generator sets are provided which generate electricity at 24 volts, and there is in addition an auxiliary storage battery in duplicate to provide against the remote possibility of a shutdown.

Incandescent Lamps for Moving Pictures

W. T. Birdsall
Westinghouse Lamp Company

THE INCANDESCENT lamp has for some time practically superseded other forms of illuminants for low power projection work requiring concentrated light sources. Recently the Mazda C lamp has been applied to moving picture work, and tests have shown that it can be made to yield even better results than the direct-current arc. The purpose of the present article is to outline the technical limitations which are encountered in making this new application.

THERE are certain differences between ordinary stereopticon and moving picture projection work. In Fig. 1 three representative rays are shown diverging from a point in the arc and brought to a focus by the condenser *1* at or within the projection lens *3*, finally becoming incident on the screen *4* at three different points, *a*, *b* and *c*. The rays from any other point in the arc will, of course, behave similarly. The light passing through the point *d* of the slide *2* is represented by three characteristic rays which are brought to a focus on the screen at *b* by the projection lens *3*. The characteristic features of this arrangement are that the transmitted light flux passes through the slide at low density on account of its great area (about 8 square inches), and the point of maximum density (the image of the radiant) occurs either in or beyond the projection lens.

The area of a moving picture film is only 0.616 square inch, and if the resulting picture is of the same size and brightness as the stereopticon picture it is evident that the same amount of light must pass through the film. This means that the film must be illuminated so as to be thirteen times as bright. To secure the enormous illumination necessary the film is placed at the most intense part of the beam, which is the image of the radiant. This is shown in Fig. 2, where an image of a point in the arc is formed on the film *2* by the condenser *1*. The rays passing through this point are again focused on the screen *4* by the projection lens *3*.

In the stereopticon, all the light from the condenser strikes the slide. If the radiant is fairly concentrated its image is smaller than the projection lens and, consequently, all of the light from the slide enters the projection lens. Thus, except for the usual losses in the lenses and slide, all of the light finds its way to the screen. Furthermore, since all of the light is used, the brightness of the picture is a function of the total lumens falling on the condenser and of no other factor. For this reason any lamp with a fairly concentrated filament will be satisfactory in stereopticon work.

In the moving picture machine, the brightness of the projected picture depends on the brightness of the image of the radiant superposed on the film. This, of course, depends in general on the intrinsic brilliancy or candle-power per square centimeter of the light source instead of the total candle-power. The intrinsic brilliancy of the crater of the carbon arc is usually figured at approximately 15 000 candle-power per square centimeter of area. The intrinsic brilliancy available in a tungsten incandescent lamp is about 2000 at 0.35 watt per normal candle-power and only about 3000 at the hitherto unheard-of efficiency of 0.30 watt per candle. To yield the same results as the carbon arc this five to sevenfold difference must be canceled by some means of increasing the brightness of the image of the radiant.

There are only two methods of solution possible and both have been utilized. The first and most important

of these consists in changing the magnification of the image of the radiant. If light from a source one square centimeter in area falls on a condenser, and thence on an image ten times as large, the light flux density in the image is, neglecting losses, only one-tenth as great as at the source. It is evident that, by changing the position of the condenser a smaller image can be formed which will be brighter in inverse proportion to its area. If the image is of constant size, just large enough to cover the

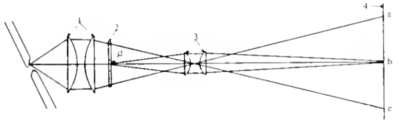

FIG. 1—STEREOPTICON PROJECTION

film, the radiant must be increased in area. Consequently, a radiant of low intrinsic brilliancy but large area can be used to replace one of higher intrinsic brilliancy and the same candle-power by changing the magnification of the image by the condenser.

The difficulties, due to the low intrinsic brilliancy of the Mazda lamp, were so magnified in the early days of the development that it is important to show why they really do not exist in this application. The beam of light projected on the film differs from the beam obtained from flood lighting or searchlight outfits, in that the angle between the edges of the beam may be fairly large. If the light passing through the film diverges ten to twelve degrees on each side of the axis, most of it will fall on the projection lens and consequently serve its purpose, while so wide a spread would be useless in a searchlight and most flood-lighting work. The searchlight problem is to render light parallel, and to do this the radiant must approximate a point source which must have high intrinsic brilliancy to produce enough light. The moving picture problem is to illuminate the film with an intensity of about 200 000 foot-candles with light which is incident throughout a comparatively large solid angle. High intrinsic brilliancy is not necessary to accomplish this.

To further increase the light on the films, devices may be used with the incandescent lamp, which collect a larger percentage of the total luminous radiation than is possible with arc lamps. Condensers must be placed so

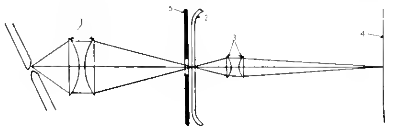

FIG. 2—MOVING PICTURE PROJECTION

far from the arc, to avoid cracking, that they rarely cover more than one solid angular unit. They can be placed much closer to the Mazda lamp so that the solid angle subtended, and consequently the light collected is larger by 20 to 30 percent. Further, an arc lamp yields its maximum candle-power in one direction, while the incandescent radiates equally from the front and back of the filament.

To sum up, therefore, the low intrinsic brilliancy of the incandescent lamp is compensated, first, by enlarging the radiant and reducing the size of its image, and, second, by collecting more of the total radiation than is possible with an arc lamp. The first method allows a thousand candle-power Mazda lamp to replace a thousand candle-power arc. The second method involves economy and increases the light obtained for a given nominal candle-power.

It would appear superficially that the arc with an efficiency of 0.17 watt per maximum candle-power should show considerable economy of power over the incandescent operating at about 0.32 watt per candle. Actually, however, the difference is in favor of the incandescent lamp. The light which is useful in projecting moving pictures is solely that from the positive crater. The intrinsic brilliancy of the crater is uniform and the area is proportional to the watts expended. The

TABLE I—CHARACTERISTICS OF DIRECT-CURRENT CARBON ARC FOR PROJECTION WORK

Amperes	Watts	Max. Hor. Candle-power	Horizontal Watts per Candle	Horizontal Candle-power due to Crater	Effective Watts per Candle
15	795	3,300	241	3,270	243
20	1060	5,000	212	4,365	243
25	1325	7,000	190	5,460	243
30	1590	9,000	177	6,550	243
35	1855	11,000	169	7,650	243
40	2120	12,500	169	8,740	243
45	2385	14,500	165	9,830	243
50	2650	16,000	165	10,920	243

light from the crater, therefore, uniformly requires the same watts per candle, and whereas the arc as a whole may require from 0.165 to 0.241 watt per maximum candle-power, the arc as used in projection work uniformly requires 0.243 watt per candle, as indicated in Table I. Further, as has been pointed out, much more light per nominal candle can be obtained from the incandescent lamp than from the arc and, on the basis of watts per unit of light delivered, the incandescent lamp is reduced to about 0.200, as compared to 0.243 for the arc.

If the losses between the mains and the lamps are included, at 40 percent for the arc and 10 percent for the incandescent, the ratio of watts per candle is as 0.405 to 0.222 in favor of the latter. An alternating-current arc delivering the same light will require from three to five times as much power as the direct-current arc, and consequently will operate, assuming 10 percent loss in the leads, at a specific consumption of about 1.10, as compared to 0.222 for the incandescent. Tests indicate that while a good average direct-current arc system of 35 or 40 amperes will throw about 0.345 lumen on the screen per watt at the arc, a simple incandescent lamp system at 0.32 watt per candle horizontal will give about 0.600 to 0.850 lumen per watt. These figures are, of course, round numbers and will vary with the construction of the lamp, the design of the condenser and the care with which the apparatus is set up.

The Application of Electricity to Enameling or Japanning

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Automobile builders and manufacturers of automobile parts are playing the leading role in the application of electricity to ovens for baking enamels or japans on metal objects. Central stations, on the other hand are increasing their power output to a considerable extent by supplying such users of electricity. This application of electric power is an ideal load builder, due to the fact that the power-factor is approximately unity and the load in many cases is practically constant. The continuity of the load will depend upon the kind and number of ovens the manufacturer has in service. With ovens of the continuous type, in which the work is hung on a moving conveyor, a definite amount of power will be required for the entire working day with only slight fluctuations for holding the temperature constant. In other types of ovens and where two or more are used, the cycle of operations may be arranged so that, as one oven is cut out of service, the other is cut in, thus maintaining a uniform load.

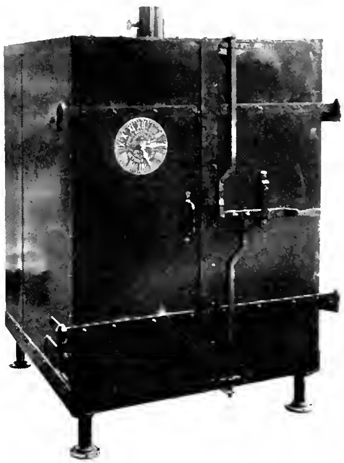


FIG. 1—A SMALL PORTABLE ELECTRICALLY-HEATED OVEN

In view of the fact that the proper application of electric heat involves a number of problems, among which are the type of oven, kind of insulating material to be used, method and cycle of operations, rate problems and installation of heaters, the earnest co-operation and assistance of central stations is especially necessary in determining the most efficient and economic way of producing the desired results.

The oven used for enameling and japanning consists of a metal-walled box or room having heat-insulating material in the walls to reduce the radiation losses to a minimum. Doors usually form one end of the oven. Heat may be supplied from any fuel, gas being that most commonly used at the present time. Gas is usually burned inside the oven, acting as the heating agent, the products of combustion being carried away through the vent pipes in the oven. Some types of burners consist of a horizontal pipe on each side of the oven near the floor with the open gas flame, while others are more elaborately constructed with housings to fully enclose the flame. Ovens equipped with electric heaters have the units arranged around the wall near the floor or on the floor itself. These electric heaters can be arranged and the number planned to meet the requirements for each particular problem. The heater itself is simply an open resistance coil having as much radiating surface as possible, and consists essentially of two steel end plates supporting top and bottom rods on which are insulating bushings. Over the bushings is wound the resistor ribbon in the form of a horizontal helix. The ribbon is one-half inch wide and is very thin, so that for a given resistance the maximum area for radiation is obtained. Suitable terminal blocks serve for making connections to the heaters.

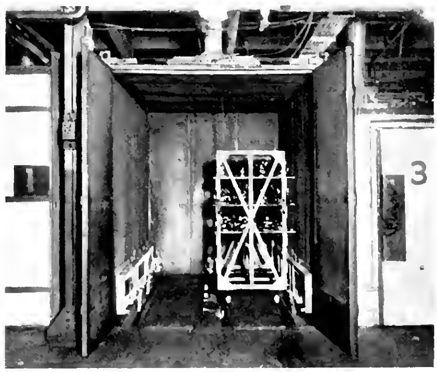


FIG. 2—ELECTRICALLY-HEATED OVEN USED FOR BAKING ENAMEL ON SMALL MOTOR PARTS

The electric heating units are mounted near the floor along both sidewalls. If a greater degree of heat is required, two or more tiers of heaters can be mounted along the walls. The oven shown is provided with tracks on which trucks for carrying the small enameled parts can be run in side by side. This arrangement allows the removal of the work while the oven is still too hot for a workman to enter.

With gas heat, the air circulation and products of combustion cause variations in the quality of enamel and a certain amount of extra work is always necessary for refinishing. The radiant electric heat, together with the absence of forced air circulation, will either reduce this to a minimum or eliminate it entirely. When gas is burned, the products of combustion, such as water vapor, sulphur compounds, grease and carbon dioxides, are formed and, while good results can be obtained in these ovens when the combustion is perfect, yet it is almost impossible to regulate absolutely the combustion of a material which varies in composition as much as the ordinary type of gas. Furthermore, a large quantity of air must be supplied to the gas which, unless thoroughly filtered, will carry with it considerable dust, which is the worst enemy of the enameler.

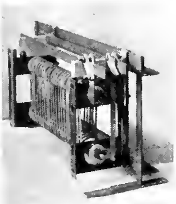


FIG. 3

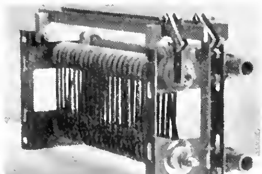


FIG. 4

FIG. 3—VIEW OF HEATER MOUNTED ON ANGLE IRON
FIG. 4—VIEW OF HEATER MOUNTED ON PIPE FRAME WORK
Showing arrangement of bus-bars, insulators and connectors.

With the electric heaters it is evident that an absolutely clean, dry heat is obtained. This gives a more perfect coating, which is baked from the metal outward and not from the surface inward, as is the case with gas or hot air heat. On account of the even distribution obtainable by proper location of the electric heating units there need be no spoiled work due to overbaking at any particular spot. It has been found that the time required for baking, to secure best quality of finish, can be reduced from 25 to 50 percent, depending upon the method of handling.

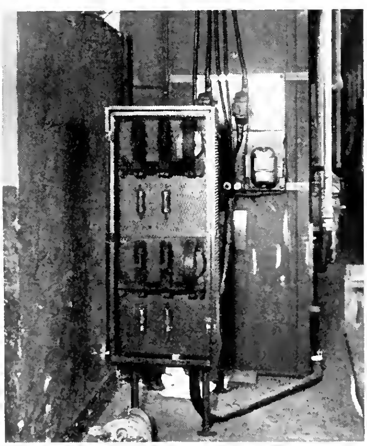


FIG. 5—CONTROL EQUIPMENT FOR A TWO-PHASE CIRCUIT

Since one of the products of baking is an inflammable gas, there is always danger of fire from any flame in the baking chamber. Furthermore, even with good construction, and proper handling, there is danger of fire or explosions in a gas oven. Naturally, this can be entirely eliminated in an electrically-heated oven. This is an important advantage and one which will be universally recognized, as it means not only increased safety to the employees and a reduction in the amount of material spoiled, but may be the cause of a marked reduction in the insurance on that part of the factory containing the enameling ovens.

For control and regulation, standard switches and switchboard construction may be used. On larger sizes, magnetically-operated switches are most desirable, as the controlling buttons may be placed most conveniently for the operators and the main switches installed in the rear of the oven, where they will be out of the way of the workers. The number of steps, or amount of heat regulation, depends entirely upon local conditions, for in some cases a single heat may suffice, while in others it may be desirable to have several steps to obtain close control of the temperature. The kind and quantity of work, together with quality of oven construction, determine this feature. Door switches may be used to turn the current off when the doors are open, and pilot lights to indicate whether circuits are opened or closed. A thermostat may be employed to limit the temperature, or to maintain it at a constant value.

TABLE I—ARTICLES THAT ARE ENAMELED OR JAPANNED

Automobile parts	Marine hardware	Metal baskets
Stoves	Tobacco cans	Lapel buttons
Metal furniture	Chemical apparatus	Instruments
Typewriters	Field glasses	Thermos bottles
Metal filing cabinets	Electric motors	Victrolas
Buggies	Adding machines	Ink stands
Art metal goods	Springs	Door knobs
Telephones	Christmas toys	Watches
Talking machines	Electric fans	Metal cages
Metal conduit	Brass beds	Tin cans
Metal signs	Cash registers	Telescopes
Knife handles	Weighing machines	

In summarizing the advantages of the electric oven over the gas-heated ovens there are several points which should be called to the attention of prospective users:—Improved quality, reduced fire hazard, increased production, better temperature regulation or control; and for the central stations:—Opportunities for increased sales of power at steady load, excellent power-factor and equalizing of load conditions.

Active co-operation on the part of the central stations is necessary for the successful application of the electric heaters in factories manufacturing enamel or japanned products. In order to accomplish this end it is usually necessary to analyze the manufacturer's production, redesign his whole system of baking and install new ovens, or re-arrange the old ones to secure the best and most economical results with electric heat.

Mechanically-Operated Gyrator Fans

E. E. Garlits

THE increasing use of oscillating fans in the last few years can be traced to two causes,—first, the desirable intermittent breeze produced, which more nearly duplicates a natural breeze than any other type; and second, the perfection of a durable and efficient mechanical device with which to make the oscillator practical. The oscillator as first designed, Fig. 1, was air-operated, depending entirely upon its own air delivery for the actuation of the oscillating device, which usually consisted of a paddle or vane mounted in front of the blades, and arranged to swing from side to side at each reversal of the motion. This type of action was short lived, principally because an outside air current might cause the oscillating vane or paddle to center itself before the blades, thus equalizing the reaction of the delivered air on the paddle, with the result that oscillation ceased until the outside air current was stopped and the oscillating device adjusted. A mechanical drive from the rotating armature was the logical design, as this form of drive is positive under all conditions and has thus entirely superseded the older air-operated device. A fan with this actuating mechanism mounted on the rear of the motor body is shown in Fig. 2.

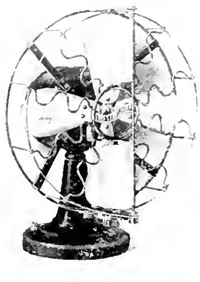


FIG. 1—OSCILLATING DESK FAN
With air-reaction oscillating device.

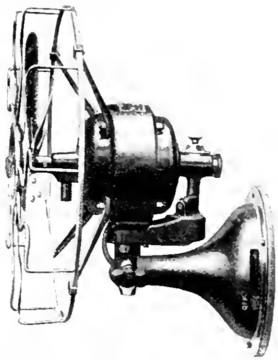


FIG. 2—MECHANICALLY-OPERATED OSCILLATING FAN

However, there are a number of applications, such as large lobbies, stores and hotels, where it is not feasible to use oscillating fans in either desk or bracket position, and for such places the large-diameter, slow-speed paddle blade or ceiling fan has been used, as shown in Fig. 3. However, the air distribution from the paddle blade ceiling fans, whether they are mounted on a ceiling, counter or floor column, is not ideal, because the air is delivered directly downward over an area not larger in diameter than one and one-half times that of the fan. The breeze outside of this area depends on re-direction by "splashing" on tables or counters or the floor within the delivered area. Although this re-direction creates considerable ventilation, it is unfortunately not greatly appreciated, since it is not as readily perceptible as is the breeze from a bracket fan. If one should come directly under a paddle blade fan the breeze would be readily felt, but in a short time the steady breeze becomes unpleasant and one generally moves away from it.

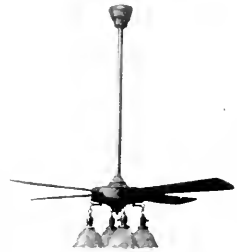


FIG. 3—PADDLE-BLADE OR CEILING FAN

For such applications the gyrating fan is ideal. The gyrating fan consists essentially of two desk or bracket fans mounted on a fixture which revolves around a central axis. These fans can be hung from the ceiling, or if the design or construction of the ceiling makes this form of mounting undesirable, they can be mounted on columns or stands placed on the floor or on a counter. Gyrating fans arranged for these mountings are shown in Figs 4 and 5. With two 12 inch fans used on the gyrator, the delivery zone will be a circle 22 feet in diameter. Air is delivered, of course, beyond this, but at

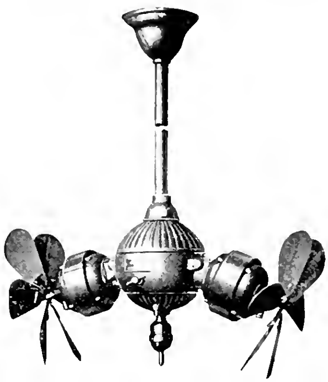


FIG. 4—MECHANICALLY-DRIVEN CEILING TYPE GYRATING FAN

feet from the fan the breeze can be felt by the hand. The strength of the breeze at any point up to 11 feet can be regulated by tilting the fans up or down on the fixture. By pointing them straight out, the breeze will be projected just over a person's head and will ventilate a large area. These adjustments are impossible with the paddle-blade ceiling fan. Then, too, the breeze from the gyrator is not steady, but is intermittent over its delivery area, and thus operates similarly to the oscillating bracket fan. In a large enclosure, such as a hotel dining-room or storeroom, a gyrating fan placed in the center of the room, or centrally between columns, will give better satisfaction than the same or a larger number of bracket oscillating fans placed on the sides of each column, as shown in Fig. 6.

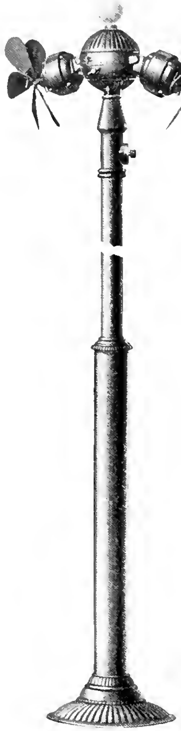


FIG. 5—FLOOR COLUMN TYPE GYRATING FAN

The development of the mechanically-driven gyrator has paralleled that of the mechanically-oscillated desk and bracket fan. The air-operated gyrating fan is affected by exterior air currents in a manner similar to the air-operated oscillating fan. However, with the gyrating fan, in

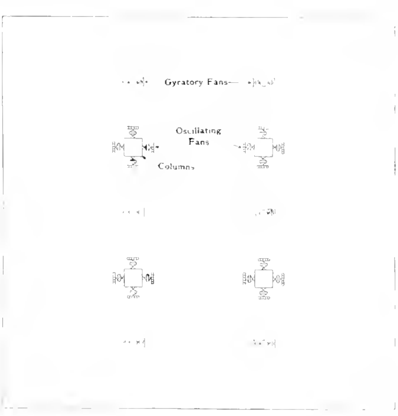


FIG. 6—TYPICAL LOCATIONS OF OSCILLATING AND GYRATING FANS
In a room 45 feet square with four columns.

addition to having the gyration stopped, the rate of gyration may be increased by the exterior air currents. For these reasons the air-operated gyrator also is being superseded by the mechanically-operated gyrator.

The reaction of the fan blades on the air-operated gyrator forms the gyrating drive, and as this reaction tends to drive the rotating fixture with an ever-increasing speed, a centrifugal device operating on a friction brake is provided to hold down the gyrating speed to normal value. This device is important, as an increase

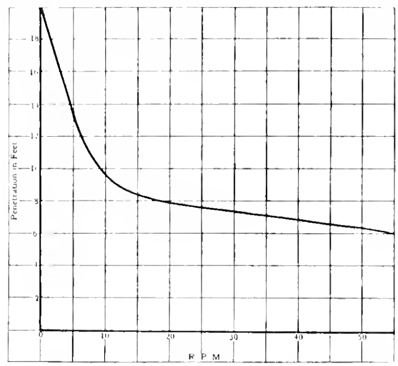


FIG. 7—PENETRATION OF BREEZE FROM A GYRATING FAN

in gyrating speed cuts down the penetration of the air stream and decreases the quantity of air delivered, as shown in Fig. 7. The best operating speed of the gyrator is between six and eight r.p.m., as at this speed the air puffs from the two revolving fans duplicate that of the oscillating desk and bracket fans. Unfortunately, centrifugal devices operate very poorly at such low speeds, and for this reason the user of an air-operated gyrator tries to adjust the friction of the brake, on which the centrifugal device acts, with the result that he usually succeeds either in stopping the gyrating motion entirely, or in decreasing the friction until the fans overspeed. Due to the change in the coefficient of friction with increased wear, it is impossible to maintain a constant friction in the friction device, and no permanent

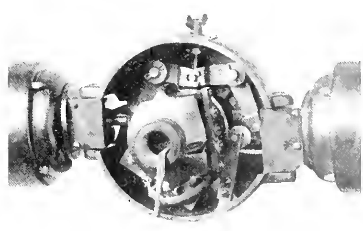


FIG. 8—DRIVING MECHANISM OF MECHANICALLY-OPERATED GYRATING FANS

adjustment is therefore possible. These fans are, therefore, just as uncertain in operation as air-operated oscillating bracket fans, and the development of the mechanically-operated gyrating fans was the logical result.

In the mechanically-driven gyrator, the drive is effected from one of the motors through a worm on the

armature shaft which operates a worm gear. A small grooved pulley is mounted on the other end of the shaft carrying the worm gear, and a steel spring belt connects this pulley with a large stationary pulley on the gyrating fixture. An idler pulley is provided to guide the belt onto the driving pulley. The range of adjustment of the bodies is from horizontal to 30 degrees below, 20 degrees being recommended as the best for average conditions. The action of the spring belt with the fan body at various angles is very peculiar. With the bodies horizontal there is no reactive force exerted by the fan blade which tends to rotate the gyrating fixture. However, the speed of gyration is slightly lower than the actual ratio between the two pulleys. This peculiar operation is explained not by slipping, but by the stretching of the belt. The tight or "pull" side of the belt is stretched as it leaves the driven pulley, and it thus travels slightly faster on this side than on the slack side, where the turns of the belt are close together. This stretching allows a half turn lag, and the rate of gyration is thus only 6.5 r.p.m. with the bodies in this position.

With the fans tilted at the maximum angle the reaction of the blades tends to revolve the fixture faster than the motor speed permits, and the motor, therefore, does not drive the fixture, but retards the gyrating speed to normal. However, the stretching of the spring belt is transferred to the opposite side of the pulleys, with the result that the heretofore driven pulley creeps ahead half a turn and the gyrating speed is 7.5 r.p.m. The tension of the belt is such that it will slip around the driven pulley and not stop the motors should the gyration be interfered with.

The tilting of the motor bodies is accomplished by a wing nut located on the revolving carrier. This wing nut operates two bell cranks, which move a pin against the lower part of the motor gear cases just below the hinge connecting the motors to the carrier, as shown in Fig. 8. The entire revolving fixture is carried on a ball-bearing and the current is transmitted through slip rings and brushes. Six-blade fans are used to insure the maximum degree of quietness, consistent with the volume of air moved.

Electric Ranges

H. C. Hopkins

THE development of the electric range has been remarkably rapid in the past two years. The types of ranges now offered to the public are many and varied and should meet all domestic requirements both as to price and utility. The central stations of the west have been particularly active in developing the cooking load, and in the past year this activity has spread to the middle west and to points in the east, where the cost of gas fuel is high. However, the widespread use of electrical energy for cooking has just begun. The high cost of operation is a disadvantage in many places and, until the central stations realize the necessity and advantage of comparatively low cooking rates, the number of electric ranges sold will not compare very favorably with the total number of ranges using gas, coal and oil fuels.

TABLE I—SHOWING WEIGHT OF MEAT SAVED BY ELECTRIC COOKING

Joint	Weight before Cooking		Weight when Cooked		Type of Oven	Loss		Percent Loss
	Lbs.	Oz.	Lbs.	Oz.		Lbs.	Oz.	
Ribs of beef	5	7	3	12	Coal	1	11	21 0
Leg of mutton	8	8	5	13	Coal	2	11	31 7
Shoulder of mutton	6	13	5	1	Coal	1	12	25 7
Leg of mutton	8	4	6	0	Gas	2	4	28 1
Ribs of beef	9	1	7	6	Electric	1	11	18 6
Leg of mutton	9	1	7	10	Electric	1	7	15 8
Shoulder of mutton	5	10	5	0	Electric	0	10	11 1

The advertising campaigns of the manufacturers, coupled with the numerous press and magazine articles telling of the advantages and economies of electric cooking have awakened the interest of thrifty housewives in all parts of the country. Domestic science teachers are advocating the use of electricity for cooking as one method of reducing the high cost of living.

It is a well-known fact that electric cooking is productive of better results, as the appearance and quality of food is superior to that obtained with either gas or coal fire cooking. Practically all users of electric ovens state that a saving is effected in weight of meats cooked, varying from 15 to 25 percent. In many hotels and club grills this increase in quality is the determining feature, and is sufficient to swing the balance, almost regardless of cost, the cost of heat of any kind being only a small

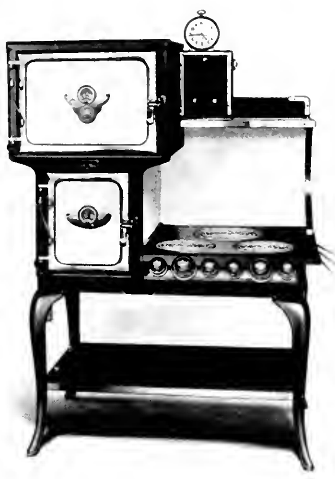


FIG. 1—AUTOMATIC WESTINGHOUSE ELECTRIC RANGE
With white porcelain enamel door panels.

percentage of the total cost of service. The data given in Table I* indicates the savings in this line which may be expected.

The success of the electric range depends, to a great extent, on its efficiency. To obtain maximum efficiency, high-grade materials and workmanship must be embodied in its construction. Simplicity of operation is also essential, as the cooking is done by hired help in a great many cases. Switches should therefore be marked so that they can be readily identified with the heaters they control.

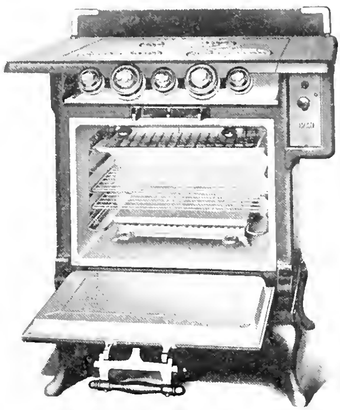


FIG. 2—AUTOMATIC WESTINGHOUSE ELECTRIC RANGE
Showing interior of oven.

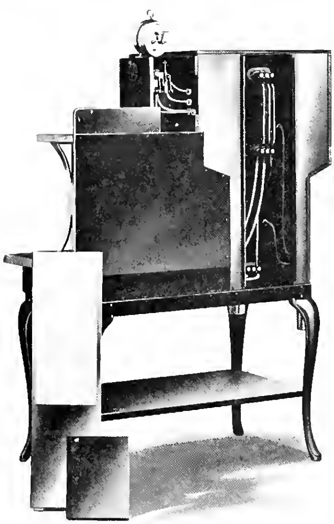


FIG. 3—ARRANGEMENT OF WIRING IN REAR OF OVENS
Showing simplicity and ease of inspection.

*From the report of the range committee of the Northwestern Light & Power Association at the annual convention at Portland, Ore., September, 1915

A study of the designs of ranges shown in Figs. 1 to 5 embodying the features mentioned above will serve to illustrate the careful attention to details necessary in the design and construction of the modern electric range. The heating units used are the open-coil radiant type, which have proven the most popular with thousands of electric range users. The average woman feels more at home with this form of heater, as she can see the coils glowing the moment the switch is turned on, just as she has been accustomed to seeing the coals glowing or the gas flame burning. The coils are assembled in porcelain

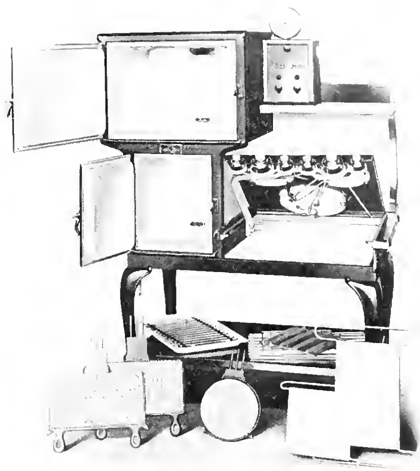


FIG. 4—AUTOMATIC ELECTRIC RANGE DISASSEMBLED
Showing ease with which all parts can be removed for thorough cleaning; also accessibility of stove top connections.

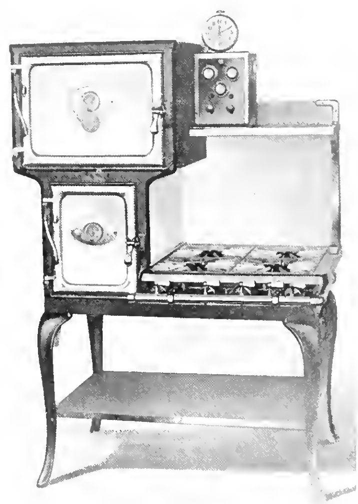


FIG. 5—COMBINATION WESTINGHOUSE GAS AND ELECTRIC RANGE

bricks, which are baked at high temperatures and will withstand the contraction and expansion due to rapid heating and cooling. The wiring to the switches on the platform heaters is underneath the heater brick and is readily accessible if repairs are needed. The oven heaters are encased in cast-iron frames, on which are mounted suitable terminals.

The fireless cooker heat storage principle is utilized to advantage in the oven construction, the walls being insulated on all sides by two inches of rock wool asbestos, thus reducing radiation losses to the minimum. As all joints are absolutely steam tight, there are no heat losses, except by radiation. The rack holders are designed to lock to each side of the oven, and all equipment can be removed and the oven cleaned with the least expenditure of energy, as there are no cracks or projections to accumulate dirt and grease.

Automatic or non-automatic control can be furnished as desired. Automatic time and temperature control is obtained by means of the circuit breaker and clock attachment, shown in Fig. 1, and the thermostats located in the oven doors. The current can be turned on either by hand or automatically by the clock, and turned off by means of the thermostat tripping the circuit breaker when the desired temperatures have been reached.

All heaters (oven and platform) are arranged for three heats, and are controlled by separate snap switches. The switches are designed so that the switch position can be read easily and at a distance. The polished nickel cases are equipped with black dials on which the switch position is marked in white enameled letters. The heater control is marked in black letters on the white porcelain handles. Polished black Russia iron is used in the outside frame, with or without nickel trimming, as desired.

It is to be expected that progressive housewives, educated to the use of up-to-date labor-saving devices, will demand combination ranges for all kinds of fuel, so that the advantages of electric ovens can be obtained. The development of the combination gas and electric range is a step in this direction. Combination ranges for the use of other fuels will naturally follow. This type of range is also especially designed to meet the demand of the combination gas and electric companies who are anxious to develop the electric cooking load but who, for various reasons, are unable to reduce their electric rates so that an all-electric range could be used economically.

The construction and equipment of the combination gas and electric range is the same as the electric range, except that gas hot plates are furnished. The gas burners are of standard construction and are the same in every respect as the burners on an ordinary gas range. A feature of the gas equipment is the automatic gas lighter. A hooded pilot light is located in the center of the four gas burners, controlled by means of a button valve on the front of the range. This light burns constantly and, by pressing down the valve, a flame is thrown over the hot plates, lighting all four burners, or any individual burner, as desired. Automatic or non-automatic control of the electric ovens is obtained by the same method as previously described.

ENGINEERING NOTES

Power Limiting Reactances

Reactance is often inserted in circuits of a large electrical system to keep down the current which will flow if a short-circuit occurs. In many machines of recent design the reactance is inherent in the machine, but some older machines need external protective reactance coils. These coils are not wound with an iron core, but on some non-magnetic core, in spite of the fact that they are intended as reactance coils. The reason is that the permeability of iron decreases as the flux increases till at saturation it is no better than air. If a reactance were designed so that the iron would not be saturated during short-circuits, an excessive amount of iron would be necessary; moreover, at normal currents the permeability of the iron would be greater than at short-circuit, and the reactance drop across the coil would be greater in proportion to the current. In other words, the drop across the coil is least in proportion to current when it is most needed. If the coil were designed with less iron it would be saturated on short-circuits and the iron would be of no advantage. Another objection to iron is that flux builds up sluggishly in it, and on short-circuits where the current wave is very steep the current would get to a maximum while the flux was comparatively small. This is due to the fact that it takes a certain amount of energy to move the iron molecules and the wave form of the exciting current for a saturated iron core is very peaked.

Reversal of Railway Motors

To reverse a direct-current motor it is necessary to reverse the relative direction of current in the field and armature. This may be done by reversing the field connections or the armature connections. Formerly it was common practice to reverse the armature. On commutating-pole railway motors it is desirable to reverse the field. Fig. 1 illustrates this point. With field reversal the commutating poles are always on the ground side of the armature. This reduces the stress on the commutating-pole coil insulation, since with armature reversal the coil is at times connected to the trolley while the pole on which the coil is mounted is grounded, thus giving full-voltage stress on the commutating-pole coil insulation.

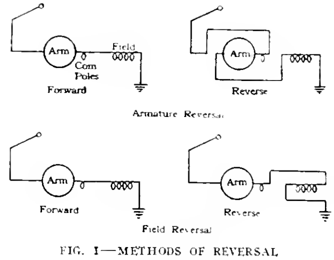
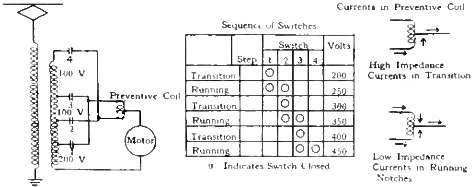


FIG. 1—METHODS OF REVERSAL

R. H. W.

Preventive Coils

The simplest way of reducing an alternating voltage for starting a series motor is by using low-voltage transformer taps. In order to change from one voltage to another without interrupting the supply of power to the motors preventive coils may be used. The preventive coil is merely an autotransformer with a tap at the center. On the first step switch *1*, Fig. 1, is closed, giving the motor a voltage equal to 200 minus the drop in half the preventive coil, which acts like a choke coil. Switch *2* is then closed. This puts the preventive coil across the main



Sequence of Switches

Step	Switch 1	Switch 2	Switch 3	Switch 4	Volts
Transition	O				200
Running	O	O			250
Transition		O			300
Running		O	O		350
Transition			O		400
Running			O	O	450

O Indicates Switch Closed

FIG. 1—USE OF PREVENTIVE COIL

transformer taps so that the voltage of its middle tap will be halfway between those of its ends. This impresses on the motor a voltage equal to $200 + (100 \div 2) = 250$. As the current goes in opposite directions in each half of the coil, its impedance is very small, causing very little potential drop. On the next step, switch *1* is opened, and later switch *3* is closed. While *1* is open and before *3* closes the motor is fed from tap *2* and half the preventive coil. If the preventive coil were omitted it would be necessary to open switch *1* before *2* closed, or else a section of the transformer would be short-circuited. If the circuit were broken to avoid short-circuit, the switches would wear fast and the car would have a jerky acceleration. Switches *1* and *3* must be interlocked so they cannot come in together, or they would short-circuit the transformer. The same applies to *2* and *4*.

R. H. W.

Automatic Slip Regulators

In cases where a motor is to be applied to a load which has heavy peaks of short duration, a flywheel can often be utilized to advantage. If the speed is allowed to decrease during the periods of peak load the flywheel will give up part of its energy, so that the load demanded of the motor is less. During the periods of light load the motor returns energy to the flywheel by speeding it up. An induction motor can be applied to such service if it has a drooping speed-torque characteristic, i. e., if its speed decreases considerably as load comes on. A high-resistance rotor will give this effect, but is inefficient on account of rotor resistance loss. This can be obviated in large machines by the use of an automatic slip regulator. This is a liquid rheostat inserted in the secondary circuit. The electrodes are operated by a motor, which is in turn controlled by the current in the main circuit. When load comes on, the current increases and causes the auxiliary motor to increase the secondary resistance by moving the electrodes or changing the level of the electrolyte. Putting more resistance in the rotor circuit reduces the current and causes the motor to give less torque or else slow down. As the motor slows down the flywheel gives up its energy to the load and relieves the motor from furnishing the whole load torque. When the peak is over the motor accelerates the flywheel, the current falls and the secondary resistance is reduced, thus obviating large secondary loss during the normal load period. See article by Messrs. W. Sykes and G. E. Stoltz in the JOURNAL for December, 1914.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1298 — **Cleaning Cooling Coils** — We have three 1000 kw, oil-insulated, water-cooled transformers. About a year ago we started to cool these transformers by means of a centrifugal pump, using water drawn from a tank, after flowing over a cooling tower. This tower is situated in a very dirty place and has considerable smoke and soot from a railroad yard blown upon it. For the last two or three months these transformers have required an unusually large amount of water and their temperatures have been higher than normal. This leads me to believe that there is a scale on the inside of the cooling coils. What do you advise doing to remove this scale? These transformers are in continuous service and I must have something that can be washed out with the cooling water. G. J. L. (NEW YORK)

Any soot or cinders would be so light that they hardly cause trouble or become scale-forming ingredients. It is likely that the repeated use of the water and consequent evaporation has largely increased the amount of total solids and led to the formation of scale inside the cooling coils. If the scale is chiefly carbonate of lime it can be removed by the use of hydrochloric acid, a ten percent solution being a convenient strength. If the scale is composed of sulphate of lime (gypsum) it may be difficult or impossible to remove it, and the best procedure is to soften the water before use and thus avoid the formation of a scale. See also No. 1237. J. L. J.

1299 — **Reading of Oscillograms** — Where can I get information as to the proper understanding of oscillograms? I have been much interested in articles that have appeared at various times in the JOURNAL and would like to know how to read the oscillograms correctly, and understand them. G. M. T. (NEW ZEALAND)

The oscillograph may be defined as a recording galvanometer which is used to determine the instantaneous values of current or voltage. These currents or voltages may have certain periodic conditions which recur exactly in a definite period of time called a cycle; or they may be some transient conditions of an electrical circuit. On the photographic record of these waves, the instantaneous values of current or voltage are shown vertically as ordinates, while the time is recorded horizontally, usually progressing in the direction from left to right. A good article on the oscillograph appears in the *Transactions of A.I.E.E.*, Vol. 24 (1905), p. 201, in which is also given an extended list of references on this subject. Two articles on the applications of the oscillograph are given by Mr. H. H. Gallecher in the JOURNAL, Vol. V (1908), p. 401, and Vol. IX (1912), p. 430. Referring to Fig. 1 of the latter article, *A*, *B* and *C* are three separate periodic conditions, which are shown as they are recorded by three separate galvanometer movements of the oscillograph. The maximum positive and negative values of the alternating voltage are given on this record by the vertical distance between the tips of the wave. Where the voltage is reduced, as at *A*, this vertical distance is smaller, because the vibration of the galvanometer has been reduced on account of the decrease in voltage. When the voltage is reduced to zero, the record simply shows a straight horizontal line. The time scale is obtained by counting the recurring cycles of the wave; this being a 60 cycle circuit, every sixth wave then represents a period of one-tenth of a second. Fig. 4 in the same article records the transient conditions which occur when a circuit breaker is used to open an electrical circuit. The voltage element records the voltage at its maximum value until the short-circuit occurs, when this value is reduced to zero. As soon as the circuit breaker opens, the element again records the maximum voltage. In this figure there is a break in the records of the three oscillograph elements about one-third the distance from the left of the figure. These breaks indicate the position where the shutter of the photographic apparatus is opened and closed. This record is revolved on a drum while the picture is being taken, and it is not always possible to open the shutter when the lap of the film is just opposite the slot in the oscillograph. To read Fig. 4 correctly, the time scale starts about one-third the distance from the left and progresses to the right edge of the figure; it is then continued at the left of the figure to the place where the records are broken. A careful reading of the three articles which have been mentioned ought to give a proper understanding of the records and uses of the oscillograph. O. W. A. O.

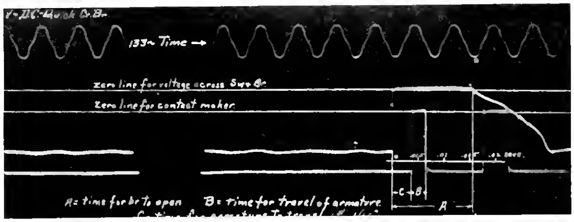


FIG. 4—OSCILLOGRAPH RECORD OF TEST ON CYCLE OF OPERATION OF CIRCUIT-BREAKER MECHANISM

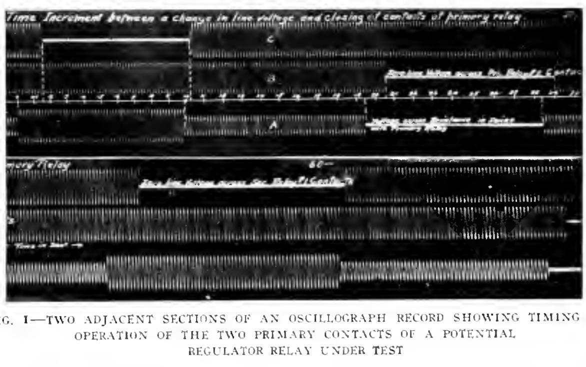


FIG. 1—TWO ADJACENT SECTIONS OF AN OSCILLOGRAPH RECORD SHOWING TIMING OF OPERATION OF THE TWO PRIMARY CONTACTS OF A POTENTIAL REGULATOR RELAY UNDER TEST

1300—**Acceptance Tests**—We are installing a vertical type, water-wheel generator. What are the usual acceptance tests and what would be the best method of drying out the machine prior to putting it in service? J. S. K. (CALIF.)

Acceptance tests made after installation are usually confined to insulation and temperature tests. Loss tests are difficult to make and are apt to be of little value, due to errors in testing. The usual method of drying out is by operating the generator with small field current and with armature terminals short-circuited. The external temperature during drying out depends on the kind of insulation used, and this question should be referred to the manufacturer of the generator. F. D. N.

1301—Field Coils on Elevator Motors—We have rewound the shunt fields of several revolving field elevator motors. The old ones are wound with No. 15 single cotton-covered wire and painted between each layer with insulating paint and then baked. There are eight coils in series of 1500 turns per coil, weight of each coil between 50-53 pounds. These coils last about two years, then the insulation gives away and the coils short-circuit. Would enameled wire be better, or what would be best to use in this case? The space is very limited. These coils are operated on 500 volts and the current varies from 3.5 to 6 amperes.
P. M. (CALIF.)

While considering a substitute for single cotton-covered wire for these field coils, the cause of its failure should first be considered. Since the field coils do not fail until after about two years, the trouble is apparently due to high temperature on the inside. If the coils were thoroughly impregnated with a compound that fills by the vacuum and pressure method, the internal heat would be more readily conducted to the surface. Enameled wire has a higher dielectric strength than single cotton covering, and also occupies less space, as well as resisting higher temperatures better. It is used on many shunt field coils. However, some kinds of enamel used on enameled wire are affected by turpentine and oil, and by many of the standard varnishes and paints, by being partly dissolved in them.
J. L. R.

1302—Voltage to Neutral of Ungrounded Lines—What is the ratio of the voltage between line and line and any line and ground on any three-phase ungrounded neutral circuit? Also is this affected by length of line, and does it make any difference if the above three-phase circuit is run direct from an alternating-current generator or from the secondary of a bank of transformers?
C. T. M. (VT.)

Assuming that the term ungrounded is taken literally and that the resistance, leakage and capacitance to ground of all insulators are the same, the voltage from line to ground will be the same in an ungrounded system as it is in a system with the neutral grounded, i. e., 57.7 percent of the voltage between phases. This is not affected by the length of line nor the source of power. In practice, however, the assumption above is never correct, and it is almost always found that the resistance, leakage and capacitance to ground of some insulators are greater than others, so that the voltage to ground over any one wire of a three-phase circuit may be anything between 57 percent of the voltage between phases and the full voltage. Under these conditions it is evident that the longer the line, the greater the chance that the leakage and capacitance to ground will be the same on all phases; hence the voltage between any phase wire and ground is more likely to approach 57 percent of a phase line on a long line than on a shorter one. In any case, a ground of relatively high resistance, such that the leakage current would hardly be noticed on the ammeters, may, nevertheless, effectively ground the circuit as long as no other grounds exist, so that on an ungrounded line there is always a possibility that the full potential of the line may exist between any wire and ground.
C. R. R.

1303—Mercury Arc Rectifier—Kindly advise me regarding the installation of a mercury arc rectifier for converting single-phase, 60 cycle, 110 volt current to direct current at 110 volts for the purpose of driving a motor which is belted to a reciprocating water pump that causes the ammeter to fluctuate between 10 and 35 amperes. Also another motor which carries 40 amperes steady. Both of these motors are shunt wound and never operate at the same time.
J. MC F (CONN)

There is no reason why a mercury arc rectifier cannot be used for the operation of shunt-wound, direct-current motors if the capacity of the motor is not such as to require more current than the rated capacity of the rectifier. Any motor, such as a series motor which requires heavy currents at times, would require a rectifier installation of such great capacity as to make it an impracticable application. The case cited in this question can be readily taken care of by the present commercial sizes of rectifier outfits, although it would probably be necessary to design an outfit especially for this service. Since there is no overload capacity for the rectifier of the present commercial type, it would be necessary to have the starting rheostat so designed as to limit the starting current to approximately the same value as the running current, as is standard practice.
A. L. A.

1304—Old Carbon Brushes—We remove a large number of worn carbon brushes each year. Is there some good use for them, other than cutting down for use in smaller brushholders? Is there not some firm who would purchase them, pulverize, and remold for use, or would it not be profitable?
R. L. T. (NEW YORK)

Scrap carbon has little, if any, value, excepting as you suggest, for cutting down into smaller brushes. We do not know of any firm who purchases scrap carbon brushes. The scrap material is usually burned up in furnaces and, in a measure, adds to the fuel value of the gas. For this reason it seems useless to attempt any salvage on the brushes as scrap material, unless you can cut them down to smaller sizes.
H. R. E.

1305—Stray Current in Rotating Shafts—Please advise how to overcome stray currents in shafts of rotating electrical machinery causing bearing trouble, if it is impossible to correct the same by insulating the pedestals.
H. M. D. (NEW YORK)

It may be necessary to insulate the dowel pins and bolts as well as the pedestal casting, but this will stop the stray currents completely. Complete insulation of one bearing is enough in the case of a two-bearing machine, and of two bearings in the case of a three-bearing machine. In the case of vertical or other bracket type machines it is, of course, the bracket which must be insulated. Usually the voltage is so low that the amount of current passing through dowel pins and bolts is insufficient to make insulation of these parts necessary.
J. L. Y.

1306—Transformer Compensation—What is meant by this statement found on the nameplate of some transformers, "Compensated for.................. Volt-Amperes?"
R. B. G. (CALIF.)

Due to losses in the transformer the ratio of primary to secondary voltage in a voltage transformer and primary to secondary current in a current transformer is not the same as the ratio of turns. Furthermore, this ratio depends to a certain degree upon the volt-ampere load which the transformer operates. This error in ratio is compensated for by changing the ratio of turns the proper amount for the specified volt-ampere load.
W. R. W.

1307—Tractive Effort—Knowing torque at one foot radius and weight, how would you figure tractive effort on the level and on grades with wheels of different size at different speeds? How would you figure drawbar pull on the level and on grades as above? What is the relation between tractive effort and drawbar pull? What should be the relation between the weight of the locomotive and the drawbar pull?
A. G. W. (WISC.)

If the known torque is that available at the motor shaft and the weight is that of the trailing load,—

Lbs. drawbar pull = $(A + R) \times T$; to accelerate on the level.

Lbs. drawbar pull = $(A + R + G) \times T$; to accelerate on the grade.

Lbs. drawbar pull = $(R \times T)$; to run on the level.

Lbs. drawbar pull = $(R + G) \times T$; to run on the grade.

Where A = pounds force per ton to accelerate, depending on the rate of acceleration (generally given in miles per hour per second and which requires a force of approximately 100 pounds per ton to accelerate at one mile per hour per second.)

R = resistance pounds per ton trailing load.

G = resistance based on 20 pounds per ton for each percent grade.

T = tons weight of trailing load.

Pounds tractive effort = $(A + R) \times T + (A + R_2) \times W$; to accelerate on the level.

Pounds tractive effort = $(A + R + G) \times T + (A + R_2 + G) \times W$; to accelerate on a grade.

Pounds tractive effort = $RT + R_2W$; to run on the level.

Pounds tractive effort = $(R + G) \times T + (R_2 + G) \times W$; to run on the grade.

Where R_2 = Resistance in pounds per ton of locomotive and W = tons weight of locomotive.

With the motor torque known and motor characteristics known, as well as the service cycle, and right-of-way conditions (track special work overhead, etc.), it is necessary to determine for each of the above tractive effort conditions the gear ratio that should be selected for a given wheel diameter.

$$\text{Gear ratio} = \frac{\text{Tractive effort} \times \text{wheel diameter in inches}}{\text{Gear Efficiency} \times 2 \times 12 \times \text{motor torque in lbs. ft.}}$$

Gear efficiency depends on type of gear, tooth form, cut or cast teeth, double or single reduction. In railway service high-grade gears are used of involute form, with cut teeth, and with a single reduction, with efficiencies of 95 to 97.5 percent; generally assumed at 96.5 to 97 percent.

From the r.p.m. curve of the known motor the motor r.p.m. corresponding to the known torque is found and the following equation determines the speeds in miles per hour:—

$$\text{Miles per hour of locomotive} = \frac{\text{motor r.p.m} \times \text{wheel diameter in inches}}{\text{gear ratio} \times 336}$$

The tractive effort equals drawbar pull plus the locomotive resistance, and the drawbar pull equals trailing load resistance. The relation between the weight of the locomotive and the drawbar pull is dependent on the track conditions (possibilities of slippery rail, weight of rail, sanded rail, climatic conditions, ballast in track), the material in the wheel tread, the adhesion between the wheel and the rail (coefficient of friction), the grades, the rate of accelerating the train, the height of the drawbar and the wheel base of the locomotive.
G. H. F. H.

1308—Polarity Test—(a) Which electrode gives off bubbles in a solution of salt and water when direct current is applied? Why? Which electrode grows smaller? (b) If two wires of a direct-current circuit are bridged by a potato will the positive lead cause a greenish tinge at the point of contact?
R. B. G. (CALIF.)

(a) When water is disassociated into its elements by an electric current the hydrogen (which in such cases is considered the metallic radical) goes in the direction of the current, namely, from positive to negative, and the oxygen goes in the opposite direction. This means that hydrogen bubbles are given off at the negative electrode. Bubbles are not given off at the positive electrode, because the nascent oxygen immediately unites with the material of the electrode. Therefore, the positive electrode grows smaller very gradually. If the electrodes are platinum or some other material which is not attacked by the oxygen, bubbles will be given off at both electrodes. (b) Yes, on the peeled potato the copper positive will show a blue-green.
C. R. R. and L. W. C.

1309—Telephone Generator—Is there made or could there be made a direct-current generator that would not cause a telephone receiver to buzz when connected across its terminals? In other words, could you use it on a telephone system without the use of batteries?
L. A. K. (CALIF.)

There is no direct-current generator manufactured which would be entirely noiseless when used for supplying current directly to a telephone circuit unless the current was passed through a large impedance coil and shunted by a heavy condenser. The storage battery serves two purposes when bridged across the generator leads. The internal resistance of the battery is so low that it keeps generator noises from passing over to the telephone circuit, and also keeps the current supply constant, without the necessity of having to run a generator continuously. The generators built for telephone work are wound so that the field coils act as an impedance coil to eliminate some of the noise that is generated by the brushes passing over the commutator. Even with these precautions the machines are sometimes noisy if the brushes are not kept practically sparkless.
R. L. S.

1310—Switching of Synchronous Apparatus—Broadly speaking, what is the maximum length of time that may be allowed an automatic oil switch to clear a defective line, without causing synchronous apparatus operated from same bus to drop out of step?
R. B. G. (CALIF.)

This will be only a few cycles—about 5 to 10 on 25 cycles and the same *length of time* on other frequencies. It depends on the load existing and on the design proportions of the apparatus. Apparatus with heavy dampers will hold in longer than apparatus with less effective damping.
F. D. N.

1311—Current Limiting Reactance—On a 15 000 volt, three-phase, delta connected system, which is sometimes grounded through a star-connection, what will be the capacity of a reactance to limit the current on a three-phase, 000 circuit to 800 amperes per wire, voltage on bus-bars remaining unaffected, in case of a short-circuit just outside of the generating station? What is this capacity known as? Give approximate outline dimensions of feeder reactances for this job. Please give an example of an order for a line reactance, using the figures above.
C. E. H. (CALIF.)

The capacity or rating of feeder reactors is fixed by the current that flows through them when the system is carrying normal load. The rating is the product of the normal current and the voltage across the terminals of the coil when carrying this current. Assuming that the normal current for the system under consideration is 150 amperes, then the voltage across the reactor at normal load would be $\frac{15\,000 \times 150}{3 \times 800} = 1630$ and the rating would be $1630 \times 150 = 244\,000$ volt-amperes $= 244$ k.v.a. This capacity is the normal rating of the reactors. In order to arrive at the dimensions of reactors it is necessary to know the frequency of the system as well as the current and voltage rating. Assuming that the above system is operating at 60 cycles, the approximate overall dimensions of these coils would be:—Overall height, 55 inches; diameter, 36 inches. The characteristics of reactors based on the above assumptions are definitely specified as follows:—Three single-phase, 150 ampere, 1030 volt, current limiting reactors to operate in a 60 cycle, three-phase, 15 000 volt circuit.
J. F. P.

1312 — Size of Locomotive — How would you calculate the size of a locomotive to bring a three-car (industrial railway) train (total 60 tons roller bearings) up to 12 miles per hour—acceleration say one mile per hour per second:—(a) on a level; (b) on a two percent grade?
A. G. W. (WISC.)

To determine the size (weight) of locomotive it is necessary to know in addition to the conditions already given the resistance of the cars and locomotive. The resistance is usually given in pounds per ton, and when it cannot be definitely determined is sometimes assumed at from 20 to 30 pounds per ton for cars in industrial service, and 10 to 20 pounds per ton for the locomotive. With roller bearings on the cars, the resistance per ton, if the bearings are properly maintained and lubricated, may not run as high as indicated above. The empty cars will be found to have a higher resistance per ton than the loaded cars (See Vol. IX, May, 1912, p. 416).

Then $W = \frac{(R + A) \times T}{F - A}$ for weight of locomotive in tons to operate on the level, where R is the resistance of the car in pounds per ton; T and W are the weight in tons of the trailing load and locomotive, respectively; F is an adhesion factor depending on the coefficient of friction (generally assumed at 30 to 33.3 percent with sand for cast-iron and steel-tired wheels, respectively, for maximum adhesion), and F equals for 33.3 percent adhesion 666.6, for 30 percent adhesion 600, for 25 percent adhesion 500, and for 20 percent adhesion 400, etc.; and A equals pounds per ton force required to overcome resistance due to rate of acceleration. When given in miles per hour per second it is assumed at 100 pounds per ton for one mile per hour per second. (The correct value being 91.3 pounds per ton force required to accelerate one ton one mile per hour per second). For operating on a grade, $W = \frac{(R + A + G) \times T}{F - A - G}$ for weight of locomotive in tons, where G equals grade resistance based on 20 pounds per ton for each percent grade. Height of draw-bar and wheel base also influence the weight of the locomotive (See Vol. VIII, March, 1911, p. 257). To determine capacity of motor, complete cycle of service and repetitions of same must be known (See Vol. VIII, Nov., 1911, p. 986).
G. H. F. H.

1313—Power-Factor Correction — We have a 450 horse-power synchronous motor direct connected to an air compressor and are 29 miles from power plant. We correct the power-factor of the line from 0.92 to unity. Can you give a formula to calculate the watts for which we are paying to correct this power-factor? Our total consumption for 24 hours is 22 000 kw-hrs.
C. E. H. (NEV.)

We cannot give any general formula to cover the case. The extra loss in the motor when correcting power-factor is due principally to more I^2R loss in the field and in the armature. This loss varies with the amount of idle current carried, but depends as well on the characteristics of the motor. To gain some idea of the value of the increased loss we suggest the following:—Under average conditions of load and power-factor note the motor field current required to bring the line power-factor to unity, and read the motor armature current A under this condition. Then adjust the motor field for minimum current input B to the motor armature. The difference between the two values of field current thus obtained, times the excitation voltage, will give an approximate value for the increased field loss. Increase this value by the ratio $A^2 \div B^2$ to account roughly for the added armature loss. Multiply this total by the number of hours per month the motor is used for power-factor correction, in order to obtain the added energy consumption in watt-hours per month.
F. L. M.

1314 — Water Wheel Horse-Power—What is the formula for finding the horse-power of a given tangential water wheel as the water pressure is decreased or increased?
R. B.G. (CALIF.)

In order to determine the amount of power available from a given quantity of water under a given head, multiply the number of cubic feet of water per minute by the number of feet of head, and this by 62.3, which equals the weight of one cubic foot of water. Divide the result by 33 000, which equals the number of foot-pounds in one horse-power, and the result is the theoretical horse-power in the water. This should be multiplied by the percentage of efficiency, which you can take as a rule as 80, which will give the horse-power available on the water wheel shaft.
J. V. K.

ERRATA

The titles to Figs. 2 and 3, p. 259, this issue, should read "30 000 kilowatt," and to Fig. 4, p. 260, should read "40 000 kilowatts."

In the May, 1916, issue, p. 200, the tenth line under Fig. 1, "The ventilating fan and rear wiper ring * * *" should read "front wiper ring * * *."

FINANCIAL SECTION

PREFERRED STOCK INVESTMENTS

Substantially all the preceding articles have been devoted to discussions of investments in bonds. We will now take up the question of investments in preferred stock issues. As already stated, the investor must always bear in mind the basic difference between purchases of bonds and of stocks. In buying the bond of a company you become a creditor of the company and have the right, in case the stipulated interest is not paid on the specified dates or in case at maturity the principal of the debt remains unsatisfied, to take steps to enforce the lien upon the property covered by the mortgage under which the bond was issued. The holder of a bond stands, or should stand, in the same relation to the corporation issuing the bond as does the holder of a mortgage given by a private individual on his real or personal property.

On the other hand, the purchaser of stock does not become a creditor of the corporation the stock of which he holds, but in effect becomes a partner with a limited liability and must take all the risks of business usually incident to a partnership. His stock certificate represents the ownership of a certain proportion of the equities of the corporation and, in case of dissolution, he would receive, after all debts had been paid, his proportion of the assets remaining after such dissolution. In almost all cases preferred stocks in the winding up of a corporation are entitled to receive up to their par value in the distribution of assets, and the common stock receives the balance, if any, remaining after the claim of the preferred stock has been satisfied.

As many companies find it impracticable to issue bonds for the full amount of new capital required, such companies obtain the balance of the required funds by the sale of common or preferred stocks, or of both. It may be that the business is such that it will not readily lend itself to a bond issue, and in this case an issue of preferred stock is made. One of the reasons for a growing partiality of many companies for the issue of preferred stock instead of bonds is that the dividend charges on the preferred stock are not a fixed capital charge on the revenues of the corporation. In the case of interest on bonds, payment must be made or the company goes into foreclosure, while in the case of dividends on the preferred stock, if they are not earned they are not paid and the holder of the stock must wait until such time as revenues of the company will produce the funds to pay his dividends.

Preferred stock is largely used in the financing of industrial and public utility companies, but not to any extent in the case of the steam railroad companies. While there are a number of issues of preferred stocks of railroad companies outstanding, almost all of these were issued by reason of reorganizations and represent stock exchanged for bonds the interest on which could not be earned. Several of these railroad preferred stocks sell now at high prices and are classed among high-grade investment securities. There are a large number of preferred stocks of industrial corporations, notably that of United States Steel Corporation, and these also are, in many instances, rated as high-grade investments.

Substantially all the leading public utility companies have issues of preferred stocks. These are steadily growing in favor with investors, as the companies are more and more demonstrating their ability to maintain a high average margin of safety over the dividends on these issues. Usually utility preferred stocks are cumulative as to dividends, which means that all unpaid dividends accumulate on the stock and must be satisfied before the common stock can receive any dividends. Just as unpaid interest accumulates to the disadvantage of junior securities, so unpaid cumulative preferred dividends pile up to the disadvantage of the common stockholder, as the holder of the preferred stock can assert his prior claim to profits up to the amount represented by the unpaid dividends due on his stock. If the profits of a company are only large enough to pay the dividends on the preferred stock, the common stockholder does not get any dividends. Unless this cumulative feature is in the preferred stock, there is in reality but little difference between the preferred and the common stocks, and it may be that it will place the junior issue on an equal plane with the senior. The management

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of the company might decide that all the profits should go back into the business until such time as the revenues were sufficient to pay dividends on both classes of stocks, in which event the holder of the preferred would be but little better off than the holder of the common.

In addition, the cumulative feature makes it certain that the dividends on the preferred will be paid, if possible. If not paid they accumulate rapidly, and within a few years would reach such proportions that their amount probably would preclude ever paying dividends on the common stock. It is for this reason that many companies have strained their resources in order to maintain dividends on their preferred stocks so that the common stocks would not be buried under an accumulation of unpaid preferred dividends. Corporations often take steps to fund these accumulated preferred dividends by asking the holder of the preferred stock to accept some other security for them, such as a debenture bond or additional preferred or common stock. Sometimes when a company finds that it cannot spare the cash to pay its preferred dividends, it asks the holders of its preferred stock to accept scrip in place of the cash. This scrip is interest bearing, has a certain maturity and often is made convertible into the stocks on attractive terms. However, either the failure to pay a preferred dividend, or its payment in scrip, puts a taint on a preferred stock as an investment which it usually requires a long period to remove, and unless absolutely necessary corporations will not take such action.

Sometimes preferred stock is participating, which means that after the preferred stock has received its stated dividend and a certain amount has been paid on the common stock both stocks will share equally in any further distributions in the way of dividends. As an example of this may be taken the preferred stock of Southern California Edison. The preferred stock was to receive cumulative dividends of five percent until such time as five percent a year had been paid on the common, and after that both stocks were to share equally in any further distribution. At the present time six percent a year is being paid on both stocks. However, in case of default in payment of dividends on the preferred stock it is cumulative only at the rate of five percent a year and not at the higher rate under the participating feature.

Preferred stocks are often made preferred as to assets, and in case this is not done the stock can be considered but little better than a common stock. Sometimes this preference is only as to the face value of the preferred stock, while in some corporations the preference as to assets includes all unpaid dividends on the preferred stock. This preference means that in case of the dissolution of a company the preferred stock is to receive its full face value out of the assets before the common stockholders receive anything. As dissolutions of corporations usually take place only after bankruptcy proceedings resulting in foreclosure of mortgages and sale of the assets for the benefit of the creditors, this provision is more a sentimental than a practical safeguard.

Preferred stock issues are often protected against any danger from a speculative dissolution of the issuing corporation or an unwarranted sale of its assets, by provisions that the directors may not dispose of the property of the company without the consent of two-thirds or three-fourths of both classes of stock. In the same way the power of the board of directors, or of the common stockholders, to mortgage or otherwise encumber the property is limited by a provision that the corporation shall not mortgage any property or create any bond issue without the consent of two-thirds or three-fourths of the outstanding preferred stock.

Sometimes in order to give the holder of a preferred stock an opportunity of participating in the profits of the company other than by the participating dividend feature, the preferred stock is made convertible into the common stock either in the ratio of share for share or on some other agreed basis. There are instances where the preferred stock has been so hedged about with restrictions that it has been made extremely difficult for the corporation to do its required financing. In the case of one company where the preferred stock is issued under an agreement that the corporation shall have no power to create any indebtedness prior to the preferred stock, the company has had to pay high rates for money obtained by the sale of debentures which were junior to the preferred issue. The company has made advantageous offers to the holders of the preferred to exchange for the common stock, but so far has been unable to get in but a small amount of the preferred, which is held as a high-class investment.

Another provision often placed in preferred stock certificates is that in case of non-payment of dividends on the stock for a period of from one year to two years, depending on the terms of issue, the common stock loses its voting power and full control of the company is given to the preferred stockholders. In other instances it may be provided that the preferred stock shall select a majority of the board of directors so long as dividends are unpaid. Such a provision exists in the preferred stock of International Mercantile Marine, and the preferred stockholders have elected a majority of the board of that corporation since its organization.

While preferred stockholders usually have equal voting power with the common stockholders, yet sometimes it is provided the preferred stock may only vote in case of non-payment of its dividends. In some cases, to guard against the danger of excessive dividends being paid on the common stock and the position of the preferred weakened, it is provided in the issue of the preferred stock that a reserve for the payment of dividends on the preferred stock must be set up before dividends are paid on the common or that, in case of payment of

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dividends on the common, these may only be paid to within a certain percentage of the actual earned surplus of the company.

Preferred stock sometimes has a redemption feature. This means that the corporation shall have the right, on giving a certain number of days' notice, to call in and redeem or pay off the preferred stock. The price at which this may be done is always fixed in the certificate of preferred stocks and may run from two percent above par to as high as 10 or 15 percent above par. Sometimes there is a sinking fund provided for preferred stock to provide for its retirement. In the case of one corporation it is provided that $100 000 of income shall be used each year for the redemption of outstanding preferred stock, which shall be drawn by lot and the certificates called in, paid for and canceled. This, of course, results in a steady growth of the equity of the common stockholders in the property, and eventually this will retire all the preferred stock.

There are several different classes of preferred stocks and the purchaser should not fail to learn just what class he is purchasing, in addition to seeing that the more important of the above provisions are included for the protection of his stock. When a company has but one issue of preferred stock it is designated as "preferred," and in other instances companies may have a first preferred, a second or even a third preferred stock, ranking in priority of claim on earnings and assets of the company as shown by their designations. In the case of issues of second preferred stock it is often provided that their dividends shall be cumulative progressively, such as two percent the first year, three percent the second year, four percent the third year, five percent the fourth year and six percent thereafter, and it also is often provided that when the second preferred becomes cumulative at the same rate as the first preferred that it shall be convertible into the first preferred, and thus the corporation will have but one issue of preferred stock. In the case of the Pacific Gas & Electric Company, that company has two classes of preferred stock, both ranking equally, however, as to dividends and assets. One issue is known as "original preferred" and the other as "first preferred." After July 1 of this year the orignal preferred will be convertible into the first preferred at the ratio of 100 shares of the former for 102½ shares of the latter, and after this conversion is made the company will have but one issue of preferred stock.

Sometimes when a company has an issue of preferred stock outstanding it may find itself in such a position that, while it requires funds, it can sell no more of the existing preferred because of low rate of earnings or small equity in the assets, and so may decide to issue a "prior" preferred stock. This stock, as its name implies, is ahead of all other stocks as regards profits and assets, and a market may often be found for such a stock when the regular preferred stock of the company is unsalable for the purpose of securing new capital for the corporation.

FINANCIAL SECTION

In addition to these various provisions which should be looked into in purchasing a preferred stock for investment, there are other factors which must not be overlooked. The position of the preferred stock in the financial structure of the company should be investigated. It may be that it is the senior security of the company and that neither bonds nor short-time notes are ahead of it. In this case it has a first claim on all assets of the corporation, as well as on its earnings. On the other hand, investigation may show that ahead of the preferred stock may be several bond issues of varying degrees of priority, and also there may be issues of short-time notes or other evidences of indebtedness.

A preferred stock investor also should always learn in investing in a preferred stock just where it stands in the financial organization of the corporation, so that he may know just what claim the stock has on the earnings and assets of the company. In the case of preferred stocks issued by holding corporations there usually are no bonds ahead of the preferred stock so far as the holding corporation is concerned, but it would be well to give some attention to the financial organization of the subsidiary companies controlled by the holding corporation and thus learn of the equities on which your preefrerd stock is issued.

Sometimes it is provided that all new preferred stock must be paid in at par and that for each share of preferred issued a share of common stock must also be issued and paid for at par in cash. Such a provision exists in the case of the preferred stock of the Electric Bond & Share Company, and is one of the principal reasons for the stable and high price at which that preferred stock sells. The preferred stock is sold to the public at par, and for each share of preferred stock issued and sold the General Electric Company, the controlling factor in the Electric Bond & Share Company, must take and pay for in cash at par a share of common stock also.

Rates of dividends on preferred stocks vary from four to as high as eight percent. The preferred stocks of many public utility companies issued some years ago bear dividends at the rate of five percent, but in later years almost all public utility stocks issued have had dividend rates of either six or seven percent, with one bearing eight percent, which, however, is now paying but four percent and allowing the other four percent a year to accumulate on the stock. There is one public utility company which has a preferred stock with a dividend rate of five and one-fourth percent, but this came about through the addition of a quarter of one percent to the stock to facilitate the exchange of another stock for the present preferred.

It is not at all difficult to figure the rate of income which will be received from the purchase of a stock. Take the price paid for the stock and by it divide the amount of return which will be received in a year from the stock, and the result will show the annual rate of income on the amount of money invested in the stock. There are a number of good public utility preferred stocks which may now be purchased at a price to give an income yield of from six to seven percent, and in some instances even higher, with a large degree of safety of both principal and income.

Earnings play a large part in the selling price of a preferred stock, and for an investment they should show that at least twice the dividend requirements have been earned over a period of years. In some instances a smaller margin of safety might be considered to be satisfactory, but in the case of public utility issues a preferred stock should not be purchased as an investment where the issuing company is not earning twice its dividend requirements. It will be found that, as the margin of safety above dividends rises, the price of the stock also increases. The highest-priced public utility preferred stock in the general market is the six percent cumulative preferred stock of American Light & Traction Company, the dividend requirements of which are being earned more than six times. The six percent preferred stock of American Gas & Electric Company is selling also at a high price, and its preferred dividend is being earned more than five times.

There is no more desirable investment for the professional or business man than well-selected public utility preferred stocks, and a diversified list may easily be made up which will return a large yield, insuring a steady income with a minimum of risk of the funds invested. In making such a list, look first to the place which the preferred stock occupies in the financial structure of the issuing corporation; how many and what bonds or other evidences of indebtedness are ahead of it; look up the dividend record and learn if there has been any cessation of dividends, and if so make close inquiry as to the reason, as sometimes a corporation may have a perfectly valid reason for a suspension of preferred dividends not at all affecting the intrinsic merits of the stock. This might be a disaster of some kind, or a sudden and world-wide financial stringency in which, for the protection of the corporation, it might have been necessary for a time to conserve all cash resources of the corporation. However, as already said, a suspension of preferred dividends always places the burden of proof on the stock to show that it is really an investment issue.

Then learn the provisions under which the preferred stock was issued, its rights in regard to assets and earnings and the position which it occupies in regard to the common stock and also its voting power. See that all the provisions safeguarding the issue of the preferred stock are explained fully and understandingly. Then take up the question of earnings. Look over the earning statements of the company for a period of from three to five years and see if the earnings have been increasing or decreasing and learn the why of the gain or loss. It may be that a sudden increase may be almost as dangerous as a sudden loss in earnings unless a good reason is given. See just the amount available for the payment of the dividends on the preferred stock and how large is the margin of safety, or the amount which will remain after the dividends have been paid for the year.

Of course, it is only in the case of the older issues that an earning record of some length of time can be secured, but in the case of any preferred stocks desirable for investment this earning record should be available. The preferred stocks issued by the new corporations stand in the same relation in the investment field as the bonds of such companies and must have some seasoning before they can be classed as investments. With the preferred stocks of old and well-tried companies available at their present prices, the investor should make his selections from these and not take up those of new and unproved companies. He will find on investigation that he can secure the former as cheaply and in many instances at a lower price than some of the newer preferred stocks which will be offered him.

DENVER GAS & ELECTRIC LIGHT COMPANY

Denver Gas & Electric Light Company has sold $4 000 000 of its first and refunding bonds and the proceeds will be used for increasing generating and distributing facilities and to refund short-time notes. Earnings of the company have been showing good gains and for 1915 net earnings were $1 652 370, or 2.6 times the requirements for interest on the entire funded debt of the company. Denver Gas & Electric Light Company has outstanding $3 500 000 six percent notes due in 1917, but they will be called for payment at 101, October 1, 1916.

PERSONALS

Mr. Charles N. Black, vice president and general manager of the United Railroads of San Francisco, has severed his connection with that company to devote his time to the interests of Ford, Bacon & Davis, of which he is a member. Mr. Black was president of the American Electric Railway Association in 1913-1914.

Mr. John B. Sebring, Pittsburgh representative of the Ward Leonard Electric Company, has moved his offices to 901 Park Building.

Mr. W. E. Skinner, consulting engineer, has opened an office at 415 Plymouth Building, Minneapolis, Minn. Until recently Mr. Skinner was president and manager, W. E. Skinner, Ltd., consulting engineers, Winnipeg, Manitoba. Prior to entering the consulting field in Winnipeg in 1907 Mr. Skinner was connected with the Westinghouse interests in Pittsburgh, Buffalo, Honolulu, Hawaii, Hamilton, Ontario and Winnipeg.

Mr. R. L. McLellan, formerly commercial manager of Merchants Heat & Light Company, of Indianapolis, has joined the Chicago sales force of the Westinghouse Electric & Mfg. Company in charge of steam railroad business in the Chicago territory.

Mr. C. P. Walker, formerly of the Los Angeles district office of the Westinghouse Electric & Mfg. Company, is now electrical engineer with the Llewellyn Iron Works and in charge of the installation of their new steel mill located at Torrance, Col.

Mr. G. E. Emmons, who has been manager of works of the Schenectady works of the General Electric Company, has been elected a vice president of the company.

Mr. H. D. James, assistant to the manager of engineering of the Westinghouse Electric & Mfg. Company, has been appointed engineer in charge of the industrial control division.

Mr. H. McD. Crawford has resigned as president and general manager of the Reading Transit & Light Company to accept an engagement with the E. W. Clark Management Association, with headquarters in Columbus, Ohio.

Messrs. Frank L. A. Graham and Ford W. Harris have formed the firm of Graham & Harris, patent attorneys, 933 Higgins Building, Los Angeles, Cal.

Mr. J. F. Briscoe, of the Cincinnati district office of the Westinghouse Electric & Mfg. Company, has resigned to enter the employ of the American Laundry Machinery Company at Cincinnati.

At the annual meeting of The Norma Company of America, in New York City, Mr. W. M. Nones was elected persident and treasurer. Prior to this Mr. Nones was secretary-treasurer, as well as general manager. In his new position he will continue to exercise the general management of the firm, which has, in five years, grown from a small import business to a commanding position among the American manufacturers of ball, roller, thrust and combination bearings.

Mr. C. C. Gray, assistant editor of the *Electrical Record,* has resigned to accept a position in the editorial division of the Westinghouse department of publicity at East Pittsburgh.

Mr. H. W. Cope, who has been in San Francisco for over a year in charge of the Westinghouse Company's exhibit at the Panama-Pacific Exposition, has been appointed assistant to the manager of engineering at the East Pittsburgh works of the company.

Mr. H. W. Hoel, manager of the Buffalo office of the A. J. Deer Company, of Hornell, N. J., has resigned to enter the employ of the Westinghouse Electric & Mfg. Company at the Buffalo district office.

Mr. C. L. Foster, formerly with the Cleveland office of the Westinghouse Electric & Mfg. Company, is now connected with the American Electric Furnace Company, of Alliance, O.

Mr. W. R. Johnson, of the mining section of the industrial department of the Westinghouse Electric & Mfg. Company, has been transferred to the El Paso district office.

Mr. G. W. Goebel, of the Westinghouse Electric Service Department, has gone to Eastern France to look after some erection work.

Mr. Harris F. Reeve, formerly connected with the Westinghouse Electric & Mfg. Company, has accepted the position of associate editor of the *Electrical Record* of New York.

NEW BOOKS

"Oxy-Acetylene Welding and Cutting—Electric and Thermit Welding"—Harold Manly. 215 pages, 56 illustrations. Published by Frederick J. Drake & Co. For sale by THE ELECTRIC JOURNAL. Price $1.00.

While the field of this book has previously been covered by other writers, nevertheless the volume has been carefully compiled and may be said to be one of the best of its kind, being intended for the practical rather than for the theoretical reader. Accordingly, it aims to give usable information freed from mathematical intricacies; and, additional to descriptions of the welding processes as indicated in the title, it contains data on thermit welding, soldering and brazing and on the alloys, gases, etc., involved in these several processes, as well as on the heat treatment of various steels. The manufacture of oxygen and acetylene are explained at some length, more particularly the apparatus required for the generation and control of the latter gas, since it is customary for the average consumer to make it direct from calcium carbide, while the oxygen is almost invariably purchased already made and compressed into suitable cylinders. Some little space is likewise devoted to the auxiliary apparatus used in oxy-acetylene welding, including the three classes of torches—high, medium and low pressure. The chapter on the actual work of welding by this process is excellent. The description of the electric, incandescent and electric arc processes of welding, while good, are not amplified to the same extent as is that on oxy-acetylene welding, and this refers more especially to the electric arc process, details of which are largely lacking. In this respect the volume could be improved in its subsequent editions, if necessary, at the expense of the chapter on blacksmith welding. The chapter on soldering and brazing is thoroughly practical. C. B. A.

"Accounts—Their Construction and Interpretation'—William Morse Cole. 430 pages. Published by Houghton-Mifflin Company. For sale by THE ELECTRIC JOURNAL. Price $2.25.

With the increased complexities and competition in modern business, detailed records and analyses are matters of large importance. While leaders in the industries have worked assiduously to organize their business on an efficient basis, in many cases they have failed to provide adequately for the fundamental means of measuring their results through a comprehensive system of accounting. In many cases business decisions have been governed by rule of thumb methods rather than with the aid of analytical accounts. Professor Cole sets forth very clearly the scientific considerations in practical accounting. The author not only discusses the principles of accounting, but presents facts regarding actual problems of the business, such as distinguishing between capital and operating costs, handling depreciation, treating capitalization, analyzing balance sheets and other important phases. Professor Cole's treatment may be profitably consulted by the business man and engineer, as well as by the accountant, as it certainly is to their advantage to follow up closely the best accounting methods in order that they maintain a properly designed system of accounts giving them data regarding their business in a clear and accurate manner. E. D. D.

"Indexing and Filing"—E. R. Hudders. 292 pages, illustrated. Published by The Ronald Press Company. For sale by THE ELECTRIC JOURNAL. Price $3.00.

While every up-to-date concern of any considerable size has its filing system, very little has been published in book form giving a comprehensive outline of the various methods of filing and indexing information for convenient reference. The present book outlines and illustrates present-day methods of filing papers with outlines as to methods of organizing a filing department. Very definite rules have been evolved for library practice, but the records of commercial organizations differ so radically from those of the library that many modifications must be made. In the present volume an attempt has been made to codify the rules governing commercial indexing of records both by the Dewey decimal arrangement and by other schemes. Various forms and current systems are illustrated. The book should be of considerable interest to anyone desiring information as to the best practice on the subject.

"Industrial Leadership"—H. L. Gantt. 128 pages, 9 charts. Published by the Yale University Press. For sale by THE ELECTRIC JOURNAL. Price $1.00.

This book is based on a lecture delivered in the Page lecture series, 1915, before the senior class of Sheffield Scientific School, Yale University. The author is well known in connection with his work in scientific management, and the present book reviews and reiterates his ideas regarding the training of workmen, principles of task work, results of task work, with a concluding chapter on production and sales. The discussion is general in its character and makes fascinating reading to any one interested in this subject.

"Practical Electrical Wiring"—John M. Sharpe. 256 pages; 152 illustrations. Published by D. Appleton & Co. For sale by THE ELECTRIC JOURNAL. Price $1.00.

This work by the instructor in the wiring department of Bliss Electrical School furnishes not only general information but sufficient special information to enable students to do actual wiring installation work. It includes in addition to elementary work of bell wiring concealed knob and tube wire sections of wiring for motors and armored cable and metal moulding wiring. An appendix is included giving data with reference to wire sizes, wire markings, conduit sizes for different sizes of wire, etc.

NEW RESISTANCE UNITS

In automobile plants, with the present great use of low-voltage equipments, battery charging, lamp dimming, etc., the demand is great for anything that promises increased efficiency in this service, and is worthy of being given the closest investigation and of having the best engineering talent devoted to the solution of the questions involved. The Ward Leonard Electric Company, of Mount Vernon, N. Y., has devoted its attention to the specific task of producing a compact unit of high resistance and a moderate current carrying capacity, combining in a small space the salient features of a strong, durable resistance unit. Their units are made of practically zero temperature coefficient wire, wound on porcelain tubes, and covered with a viterous enamel, possessing the following advantageous features:—

The resistance wire is embedded in a material which will expand and contract at the same rate as the resistance itself within the limits of usage, thus preventing the adjacent turns from closing together and short-circuiting, preventing, therefore, a change in the resistance of the unit which might cause a burnout in the circuit. The vitreous enamel in which the wire is embedded, and by which it is entirely covered, protects the wire from the atmosphere. As the entire wire is hermetically sealed it cannot deteriorate owing to the action of moisture or other corrosive elements. The coating of enamel over the wire is so thin, and the enamel so good a conductor of heat, that the heat generated is dissipated very rapidly, because the radiating surface is practically increased from that of the fine wire to that of the porcelain tube. The resistance wire has practically zero temperature coefficient, that is, its resistance does not alter with change of temperature, the importance of which is well known. These units are very strong mechanically, are small, compact, non-abrasive, rust-proof, waterproof, fire-proof and dust-proof. The terminals are very strong, and the connection between the resistance wire and the terminal leads is embedded in the vitreous enamel, which preserves the joint against any depreciation. Any of the units can be furnished with resistance as high as 10 000 ohms on one layer of wire. The Ward Leonard Electric Company's engineers solicit the opinion of automobile engineers, and will gladly take up any problems of design, mounting, etc., which they may suggest.

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The Growth of the Steam Turbine

The article in this issue on "Efficiency Tests of a 30 000 Kw Cross-Compound Steam Turbine" will be of considerable value to all who are concerned in power plant performance, as it presents in a very interesting way the trend of the economic development in power plant practice within the past fifteen years. The authors show the tremendous evolution that has occurred in the investment cost per unit of output, primarily by the use of the steam turbine, but also in an important degree by the increase in boiler evaporation effected by the use of underfeed stokers and by the use of superheated steam. By these means the original Seventy-fourth Street Plant, laid out to give about 1.2 kilowatts output for each boiler horse-power installed, now gives more than seven kilowatts for each boiler horse-power. They might also have added as an interesting item in the comparative operating cost between the turbines and the reciprocating engines, that the engine room crew previously required on one reciprocating unit of 7500 kilowatts maximum capacity is now found sufficient to operate three turbine units of 90 000 kilowatts capacity.

But above all these subordinate questions, important and interesting as they are, lies the all-important economic fact that the steam turbine has made possible the tremendous electrical development now existing in our large centers of population. Without it no such thing would have been possible as the installing of 200 000 or 300 000 kilowatts in generating capacity in one plant. Aside from the physical impossibility, it could not have been financed.

It is one of the engineering achievements of our day, equally creditable to the operating companies and to the manufacturers of power plant machinery, that our central station plants have within a dozen years or so been revolutionized so as to bring down their initial cost from one-half to two-thirds, and their operating cost from one-third to one-half. It has enabled the public utilities companies, confronted as they have been with greatly increased cost in many other directions, with more expensive labor, with higher costs on much of their material purchases, and with the many restrictions of regulative legislation, to continue to reduce their rates for their product, so that the public, accustomed to paying increased prices for most of its wants during the past fifteen years, has found in that same period a greatly reduced cost in its electrical service. The steam turbine has surely been the agent of a great public service.

It is not often that we are privileged to have before us test data of a prime mover in as complete detail as given by Messers. Stott and Finlay, or to have a test made with such care to insure accuracy. The results stand as the best recorded performance to date of any steam turbine of any size or type, and perhaps it should be emphasized that in the consideration of this design it was determined that reliability of operation should take precedence over the question of efficiency. The unit was so big and its loss from service so vital that nothing short of the greatest reliability of design in every particular could be tolerated. Therefore, in its design no special materials were required, for all the stresses are low and well within the successful practice of many years. The three units have now been in service from a year to a year and a half and have been most successful in every way.

Students of this subject will be interested to watch the future development of large turbine unit practice. Many large turbines have been purchased and will be installed within the next year. Some of them as large as these Interborough units will be of single-cylinder design. Others of about the same size will be of tandem design, having the high and low-pressure cylinders mounted on the same shaft, with a single generator. There will also be several cross-compound, two-generator units similar to the Interborough design installed in sizes of 40 000 to 45 000 kilowatts. Also, there will be installed one or more units, each of 70 000 kilowatts capacity, comprising three elements, the high-pressure in the middle and low-pressure on either side, each element having its own generator. Such a set, therefore, consists of three units, each capable of operating separately, but all three combined to constitute one very large unit, thus giving a combination of maximum efficiency, flexibility and reliability.

E. H. SNIFFIN

Silent Inefficiency

The blowing of a steam locomotive safety valve is a self-advertising form of inefficient use of power. Every engineer can recall other instances in which wasted energy attracts disagreeable attention to itself and thus acts as an automatic incentive to improved conditions in order, if for no other reason, to eliminate the distressing symptoms. Other inefficient conditions frequently persist because attention is not continually being called to them, and such "noiseless" wastes may, in the aggregate, be as serious as the more noisy ones.

An example of such "silent" inefficiency is that due to improper wall surfaces in office buildings. There are probably few people who are not aware of the fact that less light is required to produce a given illumination in a room having light walls and ceilings than in one with darker surroundings. It is usually difficult, however, to persuade building owners to spend real money to obtain an intangible and incalculable benefit. Hence, the advantage of quantitative data such as is presented by Mr. S. G. Hibben in this issue.

A. H. McINTIRE

The Hydroelectric Development of the Peninsular Power Company*

Charles V. Seastone
Consulting Engineer,
Madison, Wis.

THE LARGE demand for electric energy by the iron ore mining companies in the Iron River region of Michigan opened up the way for the hydroelectric development of the Lower Twin Falls of the Menominee River by the Peninsular Power Company. This location is about three and one-half miles north of the city of Iron Mountain. The principal points of delivery of electric energy from this plant are in the mining regions adjacent to Florence, Wis., and Iron River, Mich. The hydroelectric plant at Twin Falls and the substation at Iron River, about 36 miles distant, are connected by a three-phase, 66 000 voltage duplicate transmission line supported on steel towers. This plant is also connected by a 66 000 volt transmission line to the substation of the Iron Mountain Electric Light & Power Company.

FIG. 1—TWIN FALLS HYDROELECTRIC PLANT OF THE PENINSULAR POWER COMPANY

The original installation at the power house consisted of three 1000 kw generating units; two additional 1250 kw units were later installed, making the total capacity of the plant 5500 kw. At Iron River are located a 3400 kw auxiliary steam plant, and a substation from which the current is distributed to the mines in this vicinity.

The relative location of the dam, forebay and power house is shown in Fig. 1. The natural foundation offered by the ledge of solid rock which forms Lower Twin Falls gave an excellent location for the dam, in that the height of the dam, and therefore the amount of concrete, was thereby reduced. All the rock in this vicinity is of a granitic formation, commonly known as greenstone. The other structures, including the substructure of the power house, the forebay or canal section from which the water is carried to the penstocks, and the head-gate section containing the trash racks and penstock gates, are built on solid rock.

The maximum head, including the rock and concrete dam, is 44 feet, with an average working head of from 40 to 42 feet. The portion of the dam crossing the river proper consists of a Tainter-gate section for passing the flood flow of the river, having ten Tainter-gates, each 14 feet square. A cross-section through the Tainter-gate section, illustrating the general arrangement, design and method of anchorage of the gates, is shown in Fig. 4. This section, which is about 170 feet long, is constructed throughout of solid concrete and is of the gravity type, provided with a solid ogee section for the spillway, being flanked on the Wisconsin side by a gravity-section concrete dam. The gates are operated by hand winches which move on a track on the operating platform. In addition to this, there is an earthen section about 14 feet high and 850 feet long provided with a solid concrete core-wall, well anchored to the solid rock which underlies the surface. In addition to the flood gates, the dam is provided with an approved type fishway and a chute for the passage of logs or of floating debris. Suitable booms, anchored to heavy rock-filled cribs, extending to the bed of the river, are constructed above the dam to guide the logs to the chute.

This general plan of development, as shown in Fig. 1, was adopted because it afforded a location for the power house, which is practically free from floating materials, and because of the ease of construction of the plant.

*Revised from a paper read before the American Institute of Mining Engineers.

On the Michigan side, in the base of the Tainter-gate section, is a four by four foot sluice gate, operated by a stand on the operating platform. This gate is utilized in the winter season when it is sometimes desirable to discharge only a small amount of water, and when, due to ice conditions, the operation of the Tainter-gates is more or less inconvenient and difficult.

POWER HOUSE

The general arrangement of the power house, including the switchboard, hydraulic and electrical machinery, is shown in Figs. 5 and 6. The headgates are constructed of timber having steel-bearing plates, and each is operated by an individual hoist. Filler gates are provided in the penstock gates, although the hoists are designed to move the latter without relieving the pressure. At the end of the trash racks is a sluice gate with a movable crest, which provides means to sluice away ice or other debris that may collect in front of the racks. In the design of the hydraulic features of the plant care was taken to provide liberal areas for waterways, and so arrange the plant as to minimize the labor necessary for its economical operation.

charge turbines, are mounted in steel case penstocks and direct connected to 1000 kw Westinghouse generators. Each turbine unit, operated under an effective head of 42 feet, will develop 1700 horse-power at full gate, running at a speed of 257 revolutions per minute. The recently installed turbines are of the Leffel type connected to generators of 1000 kw capacity. A system of positive lubrication, consisting of a large grease compressor which is fitted with a suitable handwheel and gears for operating it, is installed with each turbine unit. Holyoke tests of a similar 40 inch Samson runner showed almost 80 percent efficiency at about three-quarter gate, and the manufacturer's guarantee for the wheel installed was 86.5 percent at about three-quarter discharge, that is, when developing about 1400 horse-power. Under the conditions of installation at Twin Falls power house, efficiencies somewhat greater than the manufacturer's guarantee have been realized.

The Westinghouse generators have a rating of 1250 k.v.a., 60 cycles, three-phase, 6600 volts, 257 r.p.m., each equipped with a 120 volt direct-connected shunt-wound exciter of 27.5 kw capacity, designed for operation with a Tirrill regulator. The rotor of the generator is of the

FIG. 2—MAP OF TRANSMISSION SYSTEM

The Menominee River forms part of the boundary between Wisconsin and the upper peninsula of Michigan, and flows in a southeasterly direction into Lake Michigan through Green Bay. A gauging station was established at the Homestead highway bridge, about 2.5 miles south of Iron Mountain, in September, 1902, and records are available from that time. Discharge measurements are made from the single span to which the gauge is attached.

By comparing the hydrographs of the daily flow from government gaugings of the last ten years it is found that, by the use of the pondage that is available above the dam, 2500 continuous horse-power could have been delivered during each day, except for a short period during the years 1908, 1909 and 1910. This corresponds to about 1500 continuous kilowatts delivered to the customer, allowing for losses in generators, transformers and line.

The hydraulic machinery equipment of the power house now consists of five units, two having been installed recently. The three original units, each consisting of a pair of 40 inch horizontal-shaft, center-dis-

flywheel type, so designed as to assist materially in the speed regulation of the plant. All rotating parts are designed for 60 percent overspeed.

The superstructure of the power house consists of a three-story brick building containing the switchboard gallery, individual transformer compartments provided with steel doors, high-tension switch compartments, etc. The transformer installation comprises six single-phase, 835 k.v.a., oil-insulated, water-cooled transformers, arranged in two banks, delta-connected on the 6600 volt side, and star-connected on the 66 000 volt side. Each transformer is placed on rails in a separate brick compartment closed by a steel rolling-curtain door. In the west end of the transformer building an opening is left through all the floors large enough to allow the raising of the transformer core with the aid of a triplex chain hoist attached to an I-beam on the upper floor. The cooling water for the transformers is supplied by two motor-driven centrifugal pumps, one of them being held for reserve. A complete oil piping system is installed, connecting each transformer with an oil-treating outfit of the filter-press type, so arranged as to permit

cleaning the oil of any transformer without taking the transformer out of service.

The oil switches are separately mounted and are controlled electrically from the main control board, which is located on the second floor between the two transformer groups and overlooking the generator-room floor. All high-tension and low-tension measuring transformers are placed in fireproof brick compartments, closed by asbestos doors. The individual conductors of the high and low-tension bus systems are separated by barriers of asbestos wood.

Special care has been exercised in providing for an uninterrupted service, and the equipment installed for this purpose is unusually complete and may be classified as follows:—

1—Each three-phase line is equipped with a modern type electrolytic lightning arrester.

2—Each individual overhead conductor leaving the power house is equipped with a choke coil, wound with Swedish iron to increase its resistance greatly under lightning oscillations.

3—All the high-tension stations have been wired with solid Swedish iron, for the same reason.

4—All high-voltage current transformers have been protected by special electrolytic cells.

5—A special type of arrester has been imported from Europe, in addition to the American types already installed, for the purpose of eliminating troubles due to high-frequency disturbances by lightning, switching and arcing grounds.

6—All circuits connecting with the bus-bars are provided with individual choke coils of Swedish iron to protect the machinery and station apparatus against high-frequency and short-circuit effects.

7—Two special motor-generator sets have been provided, each coupled to a heavy laminated flywheel of boiler-plate steel, to furnish emergency lighting and power to operate the oil switches in the very remote case of an accidental shutdown of the whole plant.

8—A special metallic grounding rheostat was installed between the transformer high-tension neutral and ground, together with a special current transformer, alarm bell, signal lamp, ammeter and special relays. This equipment serves, in case of accidental ground on the transmission line, to limit the ground current to a moderate amount and keep the oil switches from opening automatically, thereby maintaining uninterrupted service notwithstanding trouble on the line. The rheostat is of such capacity as to give the station operator ample time to locate the line in trouble and either isolate it or, more frequently in case of an arcing ground, interrupt service over this one line for one second (maintaining service over the other line), and thereby remove the trouble.

The transmission line leaves the power house through corrugated, porcelain outlet bushings. The line is built in duplicate and is supported on steel towers set in concrete bases. Two types of towers are used,—a flexible or two-post structure, the main members of which are channels, and a four-post tower constructed from angle sections, which serve as anchorages for the line. On all angles above 12 degrees a heavier four-post structure is used. The percentages of the different types of towers are as follows:—

Standard two-post	73
Standard four-post	17
Angle towers	9
Special towers	1

The concrete anchorages for the standard two and four-post towers were constructed by molding concrete pedestals around the base or anchorage angles. The forms for these pedestals were constructed of galvanized iron, and the work was done at convenient points along the line of construction, and the bases distributed to the sites and set. Where a line parallels a railroad and transportation is thereby facilitated, the method above outlined for forming and setting the concrete anchorages has been found to be more economical than the usual method of depositing concrete in the earth around the anchorage iron, and also gives excellent results.

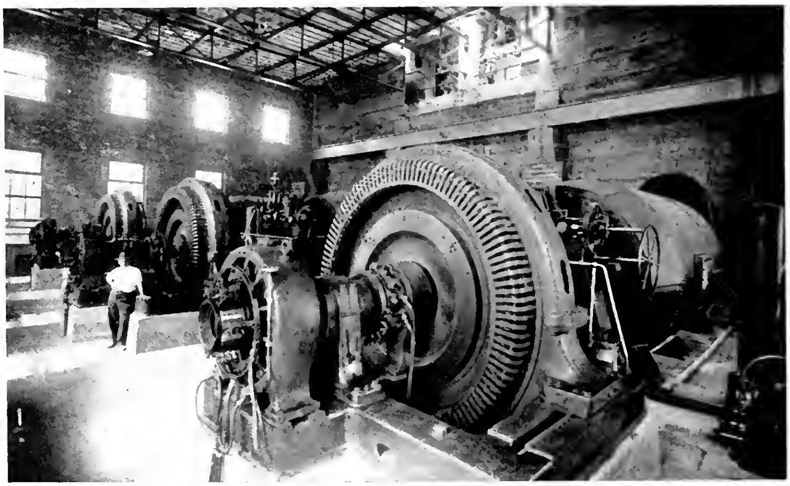

FIG. 3—GENERATOR ROOM OF THE TWIN FALLS POWER PLANT

The conductors consist of six aluminum wires, of a total cross-section equivalent to No. 0 B. & S. gauge, around a high-strength galvanized-steel center, having an elastic limit of 130 000 lb. per sq. in. The power cables are strung with a sag considerably greater than

that recommended by the manufacturers and guaranteed by them as being entirely safe under the worst possible conditions of wind and sleet loads at low temperature. This was done to get a factor of safety on the line as high as could be practically obtained.

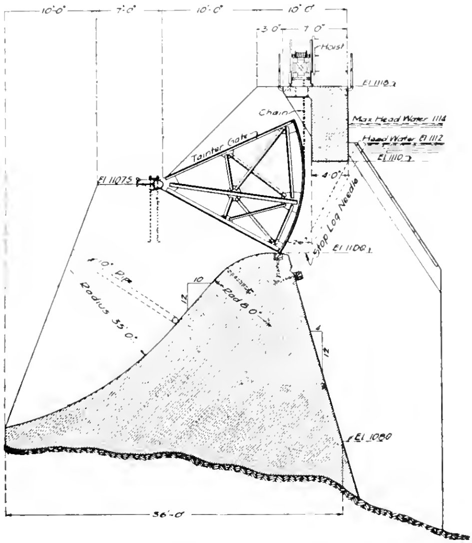

FIG. 4—CROSS-SECTION OF TAINTER-GATE AND DAM

Special care has also been taken in the design of this transmission line to provide for uninterrupted service under all conditions. The special features which will serve this purpose, in addition to those at the power plant, are as follows:—

9—The main line is built in duplicate, which always leaves the second line in service in case trouble develops on one line.

10—The transmission line is protected over its entire distance by two overhead ground wires, strung 10.5 feet above the highest power cable.

11—Each transmission tower is grounded by special ground plates below the concrete bases.

12—Each string of insulators is protected by special arcing rods arranged above and below the insulators to save them from damage by an accidental power arc.

13—The total line has been divided into a large number of separate sections, which may be easily and quickly disconnected. This will greatly reduce the time for insulating and repairing a damaged section if it should ever become necessary.

14—A private two-wire telephone line has been installed on a wooden pole line, within a short distance of the transmission line, connecting the main generating station with all the substations. The crews at the power house and all the substations are furnished with portable telephone sets which can be connected to any point of the telephone line.

With this equipment any trouble on the line can be quickly located, isolated and repaired.

The auxiliary steam plant is located just outside of the city limits of Iron River, which is central with respect to the present and probable future mining operations, and at the same time to the probable load center. The main line of the Chicago & Northwestern Railway through this section adjoins the property on the east, providing excellent facilities for the delivery of coal. Just east of the railroad right-of-way is the Iron River, a stream having a drainage area of 60 square miles and an exceptionally uniform flow, thus assuring close at hand a sufficient supply of water for condensing and other purposes.

Equipment of the steam plant consists of four Westinghouse turbogenerator units, one of 625 kw and the other three of 940 kw capacity, making a total capacity of 3445 kw. The units generate three-phase, 60 cycle, 6600 volt current.

The exciter units consist of one Westinghouse engine-driven generator and one Westinghouse steam turbine-driven generator. These units are on the main floor of the turbine room. On the main floor of the turbine room, besides the main units and exciters, are the complete substation switchboard and duplicate sets of 15 kw flywheel motor-generators for emergency operation of the control circuits and station lighting.

The main substation is at Iron River, Mich., and consists of a two-story, fireproof brick building, directly connecting with the company's auxiliary steam turbogenerator plant. It contains six 420 k.v.a., single-phase transformers of the oil-insulated, water-cooled type and the necessary switchboard and bus-bar equipment. The equipment for furnishing cooling water and that for filtering the transformer oil is a duplicate of that installed at the main generating station. The sub-station is designed to control two incoming 66 000 volt transmission

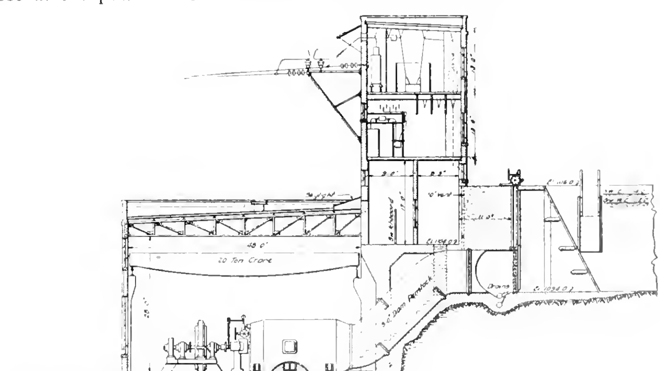

FIG. 5—CROSS-SECTION OF POWER HOUSE AND HEADGATE

lines, and four outgoing 6600 volt distribution feeders; also two banks of station light and power transformers, which also provide for all the auxiliary electrical equipment installed in the substation and adjoining power plant.

A second high-tension substation is located at Florence, Wis., ten miles from the hydraulic plant, and connecting to the main 66 000 volt transmission line. This substation supplies power to two iron mines near Florence, over a 6600 volt line carried on steel towers. It contains three 150 k.v.a., single-phase transformers, delta-connected on both the high and low-tension sides. A third high-tension substation is now in operation at Alpha, Mich., supplying power to the Judson and Balkan mines. The town of Alpha is furnished with electrical energy for general commercial lighting and power purposes. The equipment of this substation is the same as that at Florence, with the exception that the total transformer capacity amount to 900 kw.

The same type of protective equipment as is installed in the main generating station has been placed at the substations, such as electrolytic lightning arresters, individual choke coils, high-tension station wiring of Swedish iron, special electrolytic cells for protection of current transformers, high-frequency arrester, and flywheel motor-generator sets in duplicate. In addition, the 66 000 volt oil switches for the incoming duplicate transmission line are equipped with reverse power relays.

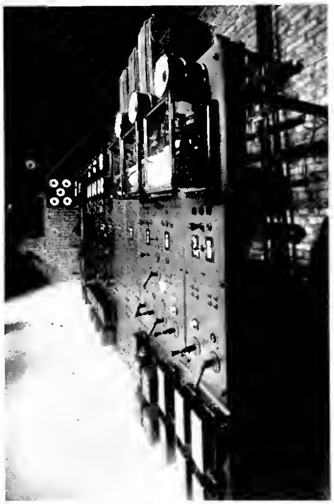

FIG. 6—SWITCHBOARD

The secondary distribution system consists of two three-phase, 6600 volt feeder circuits for distributing power to a number of mines around Iron River, and also furnishing energy to the local electric light and power plant. The entire system is built in duplicate, thereby insuring uninterrupted service to the mines.

The secondary feeder lines have also been equipped with protective devices similar to those on the main high-tension transmission line. The special protective features embodied in these secondary distribution lines are included under items *9*, *10*, *11* and *12* as classified above.

Power is transmitted to each mine substation at 6600 volts and is there transformed to 2200 volts for general distribution around the mine. The equipment of each of these secondary substations is owned by the power company and consists of three single-phase, oil-insulated, self-cooled transformers, of a capacity corresponding to the particular mine load, with ample reserve capacity for a considerable future increase of this load. The equipment comprises an automatic oil switch, a control panel with all necessary instruments, relays and measuring transformers, and a complete set of electrolytic lightning arresters and choke coils. The transformers are delta-connected on both the 6600 volt and 2200 volt sides to provide for continuity of service in case of damage to one transformer.

The secondary substations carry a typical mining load, consisting of air compressors, pumps, hoists, motor-generators for underground haulage, crushers, blowers, shop motors and lighting above and below surface. Practically all the larger motors, such as compressor, pump and hoist motors, are operated on 2200 volts, which calls for only a comparatively small investment on the part of the mine owner in step-down transformers for the lighting and small motor load, thereby maintaining at the same time a high all-around plant efficiency. In order to obtain the best possible voltage regulation over the entire system, all the large air compressors are equipped with synchronous motors, so adjusted as to give a range of power-factor most advantageous for the maintenance of a steady voltage. The maximum variation in voltage in the distribution system is about four percent.

The economic and other advantages of electric drive for mining operations have been fully realized in the district served by the power company, as is evidenced not only by the number of new mines with electrical equipment throughout, but also by the mines formerly operated by steam which are now changing to electric drive. The economy effected by electric over steam drive is most evident on the pumping operations.

A special arrangement has been made by the power company in regard to the large hoists, with their intermittent short-time loads, which had an unfavorable influence upon the total load factor of the electric mine installation, on which the rates for service are partly based. The new arrangement provides that all the large hoisting motors be supplied over a separate set of meters, which eliminates the effect of the intermittent heavy hoisting load upon the meter determining the load factor of the mine, and thereby allows the mine to earn a lower rate for power than would otherwise result. The power taken by the hoist, and also the other motors, is not charged on the basis of the actual load factor obtained at the installation, but on the more favorable basis of the load factor obtained by that portion of the load exclusive of the hoist.

Watts vs. Wallpaper

THE EFFECTS OF INTERIOR COLORS AND FINISHES UPON THE LIGHTING OF ROOMS

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WE ALL recognize in a more or less general way that dark-colored walls and ceilings absorb light, and that white or nearly white surfaces are good reflectors. But unless one has had particular occasion to study the matter, he may not realize how great an economy in the cost of artificial lighting is being overlooked by the passive acceptance of dark-colored room finishes, or how it depletes his pocketbook if he exercises bad judgment in the selection of paint or wallpaper.

When a lighting fixture is hung in an office, for example, its primary object is to illuminate the desks or table tops; secondarily, to illuminate the faces of filing cabinets or bookshelves, or wall pictures; and finally, to brighten the whole room with a moderate intensity for cheerfulness. The light rays that do any or all of these things may be classed in two divisions,—those rays reaching the illuminated object direct from the lighting unit, and those multi-reflected rays that first strike the wall, ceiling, floor or furniture, and from thence are sent eventually to the desired object.

Now ordinarily a great deal more light reaches the walls and ceilings than strikes the desk and table top direct. If this "broadcast" light is partially reflected to the table, even though half of it be absorbed in the paint or paper that it first strikes on the walls and ceiling, the remainder will approximately double the direct illumination originally received by the table. If, when using the modern types of semi-indirect bowls or diffusing globes, the room surfaces reflect 75 percent of the light striking them, then the direct light received on the table will be increased approximately four times what it would be if the surfaces reflected none of the light. If 80 percent is reflected, the light received directly will be increased nearly five times, etc.

The ratio of the light reflected from any surface, compared to that which strikes it, is its coefficient of reflection.* Were all the incident light reflected the coefficient would be 1.00. White blotting paper has a coefficient of about 0.83, or reflects 83 percent of the light striking it. If an imaginary room were considered shaped as a sphere, the light received on an object in that room would be equal to that which reached the object directly, multiplied by the factor $\frac{1}{1 - k}$, where k = the coefficient of reflection of the interior room surface. For instance, the direct illumination on a desk in such a room may be 3.0 foot-candles, when the coefficient of reflection averages 57.5. The total illumination on that desk (when aided by reflected light from all surfaces) will theoretically then be 3.0 multiplied by $\frac{1}{1 - 0.575} = 3.0 \times 2.35 = 7.05$ foot-candles.

Actually the measured illumination is somewhat less than this calculated value, because of the ordinary room being a rectangular box rather than a sphere in shape, and because of such large differences between reflecting efficiencies of the floor and other surfaces. If the room were cubical, with the floor reflecting as efficiently as the ceiling and walls, then the actual increases of illumination would closely approach the theoretical maximum of the above formula.† In any event, this example will suffice to show how greatly the direct light may be increased on account of interior colorings, considering the theoretical maximum possible increases.

Of course, no room is colored the same throughout. The walls will be darker than the ceiling, and the floor darker than the walls. Lighting units will throw different amounts of light to ceilings or walls, or be hung at varying positions. Under such variable circumstances it is better to measure the reflecting coefficients of the surfaces, and make tests of the actual illumination under the working conditions. In this way it is possible to arrive at an understanding of the influence of the surface finishes and colors upon the illumination in any particular case,—not the theoretical, but the actual.

The writer recently conducted an investigation of the performance of several different types of standard commercial lighting fixtures when installed in a typical office room measuring 16 by 21 ft. with an 11 ft. ceiling. The same conditions held during all illumination measurements, except that various colors of wall and ceiling paints were used. Some valuable information may be gathered from a study of these results. For instance, in Table I, it appears that the semi-indirect styles of fixtures are considerably dependent upon wall colorings for efficient operation, even though the majority of the light is originally directed upward to the ceiling. Even the complete indirect lighting units that send all the reflected light originally to the ceiling are materially affected by wall colorings. In the case of the indirect units the light is diffused and reflected back first from the ceiling, but quite an appreciable quantity of it strikes the walls on its journey to the table top or useful level. From Table II it is seen that diffusing globes are more influenced by

*Also termed the "Albedo" of the surface.

†Cf. "The Box Photometer," by L. O. Grondahl; Trans. I.E.S., XI, 2.

wall colorings than are the other types of glassware. This is naturally so, since such globes send as much or more light sideways than downward.

The influence of ceiling colors upon the efficiency of indirect and semi-indirect types of fixtures may be seen in Table III, where it appears that the indirect bowls are affected most, the dense glass bowls considerably, and the more translucent bowls the least. The color change is relatively slight, cream color to ivory white, yet the increases in illumination are readily noticeable.

In Table IV may be seen the combined influence of wall and ceiling colors upon open-bottom reflectors, and the difference between shallow and deep reflector shapes. Table V gives the combined effects of ceiling and wall colors on the indirect and semi-indirect units. The large percentage increases speak for themselves.

TABLE I—EFFECTS OF WALL COLORS ON THE TABLE-TOP ILLUMINATION

Indirect and Semi-Indirect Lighting Units

Glassware or Fixture	Horizontal Foot-Candles of Illumination		Increase Per Cent.
	Light Green Walls	Jersey Cream Walls	
X-Ray Bowl No. 221-T, E 150...	2.59	2.95	13.9
"Moonstone" Light Opal Bowl No. 6053....................	3.09	3.64	17.8
"Ionian" Dense Opal Bowl No. 6318......................	2.40	2.77	15.4
"Sudan" Dense Opal Bowl No. 3037 x 16	2.72	3.22	18.4
"Parian" Medium Opal Bowl No. 458.....................	2.79	3.28	17.6
"Sudan" Dense Opal Bowl No. 3031 x 14	2.29	2.78	21.4

Average increase, cream over green walls, 17.4 percent. The ceiling, for either case of wall color, remained the same, namely, ivory white. The above changes in illumination are therefore due solely to wall color. Finishes were stippled paint. This same condition applies to Table II.

The actual coefficients of reflection of the surfaces in the test room where the above results were observed are as follows:—*

Ivory White Ceiling..........................	75.9 percent
Jersey Cream Walls..........................	69.0 percent
Cream Ceiling	67.0 percent
Light Green Walls	42.2 percent
Olive Green Base Border................	21.1 percent
Maple Floor	14.6 percent
Mahogany Woodwork	2.9 percent

By comparing the actual measured increases of table-top illumination with the corresponding increases in the efficiencies of the surfaces as reflectors, it is possible to arrive at an approximate means of predicting what the final illumination will be in a rectangular room for any surface colors whose reflecting coefficients have been measured.

For example, from the first item of Table I it is seen that the measured useful illumination in the typical office room is 2.59 foot-candles from an indirect unit when the walls are reflecting 42 percent of the incident light. The illumination is 2.95 when the walls reflect 69 percent. Hence the increase of 27 percent in the reflecting power of the walls is responsible for a 14 percent increase in useful illumination. Tabulating the data from all the five tables, Table VI is obtained.

TABLE II—EFFECTS OF WALL COLORS ON THE TABLE-TOP ILLUMINATION

Totally Enclosing Diffusing Globes

Glassware	Horizontal Foot-Candles of Illumination		Increase Per Cent.
	Light Green Walls	Jersey Cream Walls	
"Parian" Medium Opal Globe No. 7812....	2.47	3.18	28.8
"Chatham" Light Opal Globe No. 2065......	2.49	3.19	28.1
"Delica White" Opal Globe No. 775...	2.65	3.24	22.3
"Delica White" Opal Globe No. 748	2.03	2.60	28.1

Average increase, cream over green walls, 26.8 percent. Ceiling in both cases of wall color was ivory white.

TABLE III—EFFECTS OF CEILING COLORS ON THE TABLE-TOP ILLUMINATION

Indirect and Semi-Indirect Lighting Units

Glassware or Fixture	Horizontal Foot-Candles of Illumination		Increase Per Cent.
	Medium Cream Ceiling	Ivory White Ceiling	
"Cora" Cased Opal Bowl No. No. 1270½................	2.76	3.03	9.8
"Moonstone" Light Opal Bowl No. 6053..................	2.88	3.09	7.3
"Sudan" Dense Opal Bowl No. 3037 x 16.......	2.40	2.72	13.3
"Ionian" Dense Opal Bowl No. 6318.	2.01	2.40	19.4
"Lenox" Light Opal Bowl No. 3018......................	2.86	3.07	7.4
"Delica White" Cased Opal Bowl No. 8077..................	2.72	2.96	8.8
"X-Ray" Indirect Bowl No. 221-T, E-150................	2.16	2.59	19.9
"Sudan" Dense Opal Bowl No. 3031 x 14...........	2.14	2.29	7.0

Average increase, ivory white over cream ceiling, 11.6 percent. Walls, in both cases of ceiling color, a light green.

TABLE IV—COMBINED EFFECTS OF CEILING AND WALL COLORS ON TABLE-TOP ILLUMINATION

Open-Bottom Diffusing Glass Reflectors

Glassware	Horizontal Foot-Candles of Illumination		Increase Per Cent.
	Cream Ceiling Light Green Walls	Ivory-White Ceiling Cream Walls	
"Alba" Shade No. 3463.....	2.35	2.92	24.3
"Chatham" Shade No. 2008	2.85	3.20	12.3

The first reflector, of a shallow-bowl type, allows more direct light to strike the walls. The second, of a deep-bowl shape, allows less light to strike the walls and is least influenced by the surroundings.

*The reflected light being measured at an angle of 30 degrees from the normal. Incident light (tungsten lamp) normal to the tested surface.

TABLE V—COMBINED EFFECTS OF CEILING AND WALL COLORS ON TABLE-TOP ILLUMINATION

Glassware or Fixture	Horizontal Foot-Candles of Illumination		Increase Per cent
	Cream Ceiling Light Green Walls	Ivory-White Ceiling Cream Walls	
"X-Ray" Bowl No. 221-T, E150	2.16	2.95	36.6
"Moonstone" Light Opal Bowl No. 6053	2.88	3.64	26.4
"Ionian" Dense Opal Bowl No. 6318	2.01	2.77	37.8
"Cora" Cased Opal Bowl, No. 1394½	2.95	3.70	25.4
"Sudan" Dense Opal Bowl No. 3037 x 16	2.40	3.22	34.2
"Sudan" Dense Opal Bowl No. 3031 x 14	2.14	2.78	29.9

Average increase, light-colored over original interior, 31.7 percent.

TABLE VI—COMPARISON OF TABLES I-V

	Percent Increase in Reflecting Coefficients		Percent Increase in Useful Illumination
	Of Ceiling	Of Walls	
Table I—Bowls	....	27	17.4
Table II—Globes	....	27	26.8
Table III—Bowls	9	...	11.6
Table IV—Shades	9	27	12 to 25
Table V—Bowls	9	27	31.7

indirect or semi-indirect lighting units, but also the wall colors must be reckoned with, for the walls have a larger influence upon the final illumination than is commonly supposed.

The use of the Mazda C lamps in small room lighting has extended greatly the application of the indirect and semi-indirect types of fixtures. Heretofore much emphasis has been put upon the value of efficient ceiling colors in order to redirect the upward reflected light back towards the floor, but little has been said of the influence of the walls upon the results obtainable with such fixtures. If the semi-indirect bowl is of medium or light density glass, the wall colors should be given nearly as much weight as the ceiling colors if best ultimate efficiency is sought.

TABLE VIII—TYPICAL ROOM FINISHES

Building	Room	Surface	Percent Efficiency of Reflection
H. W. Oliver Building.	Typical Outside	Green Walls	42.2
		Olive Dado	21.1
		Mahogany Trim	2.9
	Corridors and Toilets	White Marble	61.8
		Maple Floor	14.6
	Test Room No. 1316	Ivory White Ceil'g	75.9
		Jersey Cream Walls	69.0
Century Building	Corridors	Buff Walls	56.3
		Dark Red Dado	7.0
	2d Floor Show Rm.	Light Green Walls	25.2
	Typical Outside	Med. Cream Walls	56.3
Westinghouse Building	Corridors	White Marble	56.3
	Typical Room	Dull Green Walls	15.5
	Electric Journal	Med. Green Walls	16.7
Keenan Building	Typical Office	Cream Walls	61.8
		Light Cream Ceil'g	67.5
	Chamber of Com'ce	Dark Green Walls	8.5
Carnegie Building	Typ'l Outside Rm.	Gray-Green Walls	49.5
	Inside Room	Lemon-Yel. Walls	70.2
Frick Building	Typ'l Outside Off'ce	Medium Buff	57.5
	F. H. Heywood Off	Cream Walls	67.5
		Dark Cream Dado	53.4

TABLE VII—LIGHT REFLECTING POWERS OF VARIOUS COLORED SURFACES

SURFACE	Composition by Percent Weight												Comparative Coefficients of Reflection (Incident Light at 45 degrees, Clear Tungsten Lamp, Flat White Taken as 100 Percent)			
	Linseed Oil	Turpentine	Shepards Permanent White	Raw Umber	Raw Sienna	French Ochre	Keystone Flat White	Pierces Ivory Black	Masurys Chrome Yellow Orange	Wrinkles Chrome Yellow Medium	Chrome Yellow Light	Chrome Green Light	Normal to Surface Coeff.	Normal to Surface Rank	45° Angle to Surface Coeff.	45° Angle to Surface Rank
Enamel White	"Mooranel"—100 percent												110	1	122	1
Bare Plaster													106	2	111	2
Flat White							100						100	3	100	4
Ivory White					0.9	...	99.1						99	4	108	3
Light Buff Ceiling	1.60	13.54	84.1			0.76							88	5	91	5
Light Green Ceiling	1.65	10.81	87.3								0.092	0.182	85	6	88	6
Yellow Ceiling	1.60	13.16	83.95		..	..	..			1.29			83	7	85	7
Light Grey	1.62	12.19	86.15		...	..		0.043					79	8	84	8
Buff Ceiling	1.53	13.34	80.8			4.37							79	8	83	9
Medium Buff Wall	1.50	17.54	79.1	0.14	..	1.44			0.32				77	9	80	10
Dark Grey	1.50	13.81	84.36	..	...	...	..	0.24					62	10	66	11
Medium Green Wall	1.55	13.95	81.0									2.51	54	11	58	12
Dark Buff Dado	1.39	15.57	74.5	0.86		6.72			1.99				54	11	57	13
Straw Green	1.37	16.21	72.3	2.15		7.66						2.28	45	12	48	14
Dark Green Dado	1.47	10.69	78.0	...	...	2.95	...	...				0.89	36	13	41	15

Before attempting to generalize, the author would prefer more extensive data, but it appears from these tests that where diffusing globes are used to illuminate a moderate-sized rectangular room the useful illumination will be increased by a percentage nearly equal to the increase in the reflecting coefficient of the walls. Where semi-indirect bowls are used, the illumination is increased by a percentage roughly one-half that of the increase in wall reflection, and by a percentage equal to or a little greater than the increase in ceiling reflection.

One fact stands out prominently. Not only must the reflecting values of the ceiling be considered when using

A word of caution should be given, to warn against the use of enameled or glazed surfaces when painting office rooms, for only in extreme cases do such finishes increase the useful illumination, and in nearly every case they cause glare, specular reflections and unpleasant interiors. The common method of obtaining the matt or stippled paint finish is by the use of a short-bristle wire brush applied to the surface before the paint

is dry. Data as to the compositions of some common paint mixtures and the values of the various mixes as light reflectors are given in Table VII.* What has been said about paints will apply equally well to wall papers. The residence owner is needlessly extravagant who uses dark paper, and then pays for larger lamps and more wattage than would otherwise be necessary.

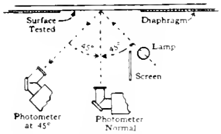

FIG. 1—POSITION OF PHOTOMETER FOR READINGS GIVEN IN TABLE VII

In every city and in every building there are wide ranges of colors used in office and similar rooms. A few typical examples in the city of Pittsburgh are given in Table VIII. Some colors as listed above, or found in use, are a great deal darker than seems necessary or advisable. It is not advocated that rooms be finished in white, for in addition to the difficulty of maintenance, the tiring effects upon the eyes would condemn this color. But it is advocated that where walls reflect less than 50 percent of the incident light, and ceilings less than 70 percent, the owner or tenant look towards a color change. It is more than likely that an appreciable savings in the cost for lighting can thereby be effected, and the operating costs reduced without sacrificing artificial illumination. Furthermore, the daylight illumination will be correspondingly increased and the hours of artificial lighting shortened.

*An investigation directed by Mr. F. H. Heywood, Union Arcade, Pittsburgh.

Automatically-Controlled Feeder Voltage Regulators

E. E. Lehr and I. C. Minick

INDUCTION-TYPE feeder voltage regulators have come into general use by central station operating companies, and the installation of this type of regulator tends to keep pace with the growth in alternating-current feeder lines and distribution networks, particularly on the systems of the larger stations. With the continuous increase and extension of distributing systems, especially for supplying lighting service to outlying residential districts, the installation of feeder regulators has proven a necessity for maintaining constant voltage at distributing centers, aside from any other advantages that may accrue from their use. Under such conditions it is found that considerably less expense is incurred in the maintenance of constant voltage at the distributing center by means of feeder regulators than by the addition of line copper. In fact, the addition of line copper cannot eliminate the line drop and is, therefore, a very inefficient way of improving the regulation. For example,—assume a feeder having ten percent voltage drop at full load due only to the resistance of the line. If copper were added so as to double the total line copper, the line drop would only be reduced from ten to five percent. Since some of the drop is necessarily due to the inductance of the line, the improvement in regulation would be even less.

In addition to the immediate requirement of maintaining constant voltage at the supply end of the feeder in order to provide satisfactory service, the proper application of induction regulators results in direct benefits to the central station. These benefits are:—

1—The increased revenue derived from the increased wattage consumption of lamps, heating appliances and other power-consuming devices when the voltage is held normal during peak-load periods.

2—The increased life of incandescent lamps when not subjected to over-voltage which frequently occurs at periods of light load.

3—The possibility of increasing the load on normally loaded feeders without the necessity for adding heavier conductors to neutralize the voltage drop.

Because of the increasing importance of the feeder regulator, a considerable amount of engineering investigation and experimental work has been carried out with a view to the further improvement of the induction-type regulator from the operating standpoint. Refinements of certain details of design have been made, resulting in improved electrical efficiency, simplification of accessories for automatic control and increased reliability in service.

Following the tendency in other lines of power apparatus, steel has been substituted for cast iron where practicable. Single-phase units of the more commonly used sizes are now built with the so-called frameless type construction which is largely used for induction motors. With this type of construction, the cross-section of the magnetic circuit is increased without increasing either the size of other parts or the floor space, but the iron loss and exciting current are correspondingly reduced.

A regulator of recent design is shown in Fig. 1, removed from the tank in which it is immersed in transformer oil for operation, and the regulator mounted in a sheet-steel cast-in tank is shown in Fig. 2. This regulator has a laminated steel stator core assembled and rigidly clamped between steel end plates by heavy steel rods passing longitudinally through the core at the corners of the punchings. This forms a compact unit, of a convenient shape for winding. Fig. 3 shows the core after the stator windings are in place.

The primary core or rotor is likewise built of steel punchings, these being assembled on a cast-iron spider and clamped between finger plates, as shown in Fig. 4. This spider is pressed on a heavy steel shaft having

ground bearing surfaces. For small regulators the punchings are built up directly on the shaft. The copper loss in the short-circuit windings of single-phase regulators of the type shown has also received attention. Instead of using one or a few turns of a solid or bare

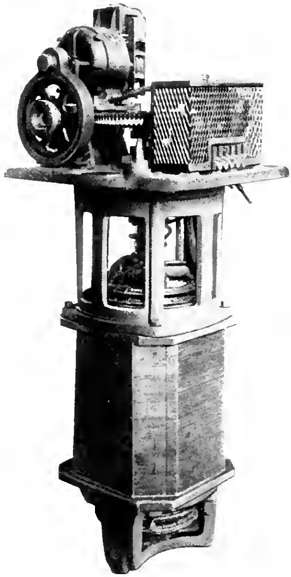

FIG. 1—AUTOMATICALLY-CONTROLLED, INDUCTION-TYPE FEEDER VOLTAGE REGULATOR
With tank removed.

stranded conductor, many turns of small-sized enamel wire are used and a material reduction in the loss is effected.

Open slots are used in both the rotor and stator punchings except for the short-circuit windings of

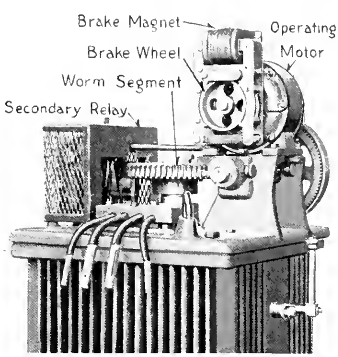

FIG. 2—AUTOMATICALLY-CONTROLLED REGULATOR
Mounted in a sheet-steel cast-in tank.

single-phase regulators. Here no advantage is gained by the use of form-wound insulated coils, and partially closed slots are therefore used to reduce the magnetizing current as much as possible. The form-wound coils are held in position by hard fiber wedges in small grooves at the top of the slots, as shown in Fig. 4.

To prevent vibrations which would otherwise occur in single-phase regulators because of the magnetic action between the rotor and stator cores, special methods of machining the end frames and bearings are employed to secure perfect alignment of the bearings and accurate centering of the rotor shaft. The stator punchings with end plates are carefully built up on an expanding mandril and riveted together. Before remov-

FIG. 3—LAMINATED STEEL STATOR CORE
With the stator windings in place.

ing the mandril the stator is placed in a lathe and finishing cuts are taken on the bearing surface between the stator and brackets, thus insuring the best possible alignment and a uniform air-gap. Also a heavy rotor shaft with long bearing surfaces is used to secure rigidity. These features of design have successfully overcome vibration, and the modern regulator operates quietly and presents no difficulties due to vibration.

Regulators operate in most cases under severe conditions as regards both voltage and mechanical strain on the insulation of the coils. Unlike most other types of power apparatus, the regulator carries the entire load on the feeder through its secondary winding and frequently has no protection other than an oil circuit-breaker. It is, therefore, subject to voltage strains from surges, static or other line disturbances, and in addition the secondary coils receive the mechanical shocks resulting from heavy current rushes due to short-circuits oc-

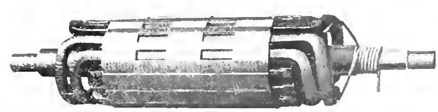

FIG. 4—PRIMARY CORE OR ROTOR
Laminated and assembled on cast-iron spider.

curring on the line. If the regulator is installed in or near the generating station, the rush of current through the secondary coils during a short-circuit may reach an excessive value and result in violent mechanical forces n the windings, tending to distort the coils and badly injure the insulation.

Because of the severe service conditions the coils of feeder regulators are form-wound and very carefully insulated, especial care being taken to secure sufficient

mechanical strength to resist bending or twisting under strain. The tendency of a heavy surge of current passing through the stator winding is to bend the ends of the coils extending beyond the core slots backward away from the rotor. Such bending would result in cracking the impregnated insulating materials and probably lead to a failure of the insulation of the coils to the iron core or short-circuit a number of the turns in the coil. To strengthen the coils against distortion from current rushes, a recent improvement is to use bracing rings formed from steel rod of circular cross-section thoroughly insulated, which are securely bound over the ends of the coils, as shown in Fig. 3. These rings add a high degree of stiffness to the coils and, therefore, increase the factor of safety of the regulator against failure in operation. The installation of preventive reactances connected in series with the feeder wires on the load side of the regulator will also prove a valuable safeguard on many circuits. When a short-circuit occurs near the station on a feeder connected to the bus-bar of a large generating plant, the instantaneous current which may flow is so large, and the resulting magnetic stresses in the windings are so great, that it is not practical to

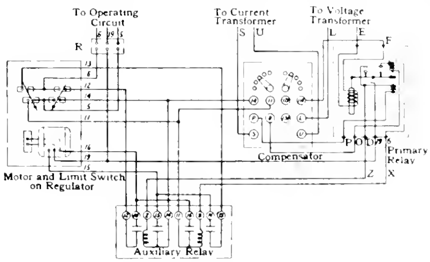

FIG. 5—CONTROL DIAGRAM OF AUTOMATICALLY-CONTROLLED REGULATOR

With auxiliary relay mounted separately.

provide sufficient protection within the regulator to take care of these enormous stresses. For such conditions separate current limiting reactances should be provided. These are desirable not only to protect the regulator, but also to protect the feeder itself against extremely destructive short-circuits.

The latest regulators are automatically controlled by means of a voltage regulating primary relay and an electrically-operated motor switch commonly called an auxiliary or secondary relay. A line drop compensator with the necessary current transformer, and a voltage transformer for reducing the line voltage to a value suitable for the primary relay, are the accessories normally required for automatic operation.

In order to simplify the control wiring, and thus lessen the chance for failure in the control circuit, a modification of the secondary relay has been recently made whereby the limit switch used to stop the motor, in case of failure of one of the relays, and thus prevent overtravel of the regulator, is incorporated as a part of the relay, and the whole is mounted on the regulator top cover. Formerly the limit switch was mounted on the regulator cover and the auxiliary relay was mounted separately. It is possible, even with a separately mounted auxiliary relay, to use but five control wires to the regulator, but the motor would not have the protection against burnouts that is provided by the above connections. With separate relays and but five control wires, if the regulator is turned back so as to start to close the limit switch again after the limit switch trips, it is possible to stop the regulator with the limit switch in such a position that, when an attempt is made by means of the relay to operate the regulator in one direction, single-phase current only will be connected to the motor, and as the motor will not start it may be burned out.

When the connections are as shown in Fig. 5, the limit switch is so constructed that the circuits from *5* to *14* and from *5* to *11* are always opened before the circuits from *6* to *12* or from *6* to *13* are opened. In closing, the reverse action takes place, i. e., the circuits *5* to *14* or *5* to *11* close last. Since the operating coils of the auxiliary relay get their current through leads *14* or *11* the auxiliary relay cannot operate until the circuits are

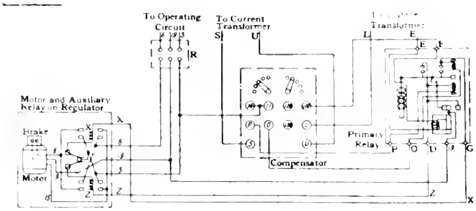

FIG. 6—CONTROL DIAGRAM OF AUTOMATICALLY-CONTROLLED REGULATOR

With auxiliary relay mounted with limit switch on regulator cover.

completed so that single-phase current alone cannot be connected to the motor.

In Fig. 6 is shown the control diagram of the automatically-controlled regulator, shown in Figs. 1 and 2. Five control wires only are brought out from the relay, but the motor is protected from the possibility of having single-phase current connected to the motor (except as a result of a defective supply circuit or defective apparatus), since the motor is stopped by interrupting the current to the operating coil of the auxiliary relay. Regulators are frequently operated (especially when being installed) by pushing in the auxiliary relay contacts by hand. Since the opening of the circuit to the operating coil would not stop the motor in this case, it would be possible for the regulator to overtravel and jam the worm. To prevent this a device is arranged to mechanically open the auxiliary relay contacts if for any reason the auxiliary relay does not open when the circuit to the operating coil is opened.

Efficiency Tests of a 30 000 Kw Cross-Compound Steam Turbine

H. G. Stott and W. S. Finlay

IN THE JOURNAL for June, 1915, Mr. M. C. McNeil gave a description of the 30 000 kw turbogenerating sets which were at that time being installed in the Seventy-fourth Street Power Station of the Interborough Rapid Transit Company. The following article, in the form of extracts from a paper presented by Messrs. H. G. Stott and W. S. Finlay before the American Society of Mechanical Engineers, May, 1916, together with additional points presented in the discussion by the authors, gives complete test data with regard to the operating efficiencies of what is at once the largest and most efficient units which have yet been tested.—[ED.]

THE determining factors in the selection of power generating equipment present about as many variables as there are installations. Engineering experience has practically standardized the electrical end. The steam engine, on the other hand, does not seem to have been capable of such standardization, as engineers are not agreed as to the most desirable superheat, pressure, etc., which must be considered both from the standpoint of reliability and boiler and engine economy. This thought is more than ever pertinent at this time, as it appears that we are on the eve of the employment of higher pressures and perhaps even new systems of power generation. Further, the capacity of the machine to be selected and the relation of point of best steam consumption to maximum continuous load and provision for heavy overloads for limited periods are all dependent on load factors, diversity factors, etc., which present a new problem for every installation.

Without detailing at length the considerations which led to the selection of three 30 000 kw units for the Seventy-fourth Street Station of the Interborough Rapid Transit Company, a brief summation of the main questions involved will possibly serve to classify the installation properly. The prospective daily plant load could be best provided for by units of 30 000 kw maximum continuous capacity each. Economic considerations warranted the withdrawal of the horizontal-vertical double cross-compound engine-generator sets installed at that time, and their replacement by more efficient and larger units.

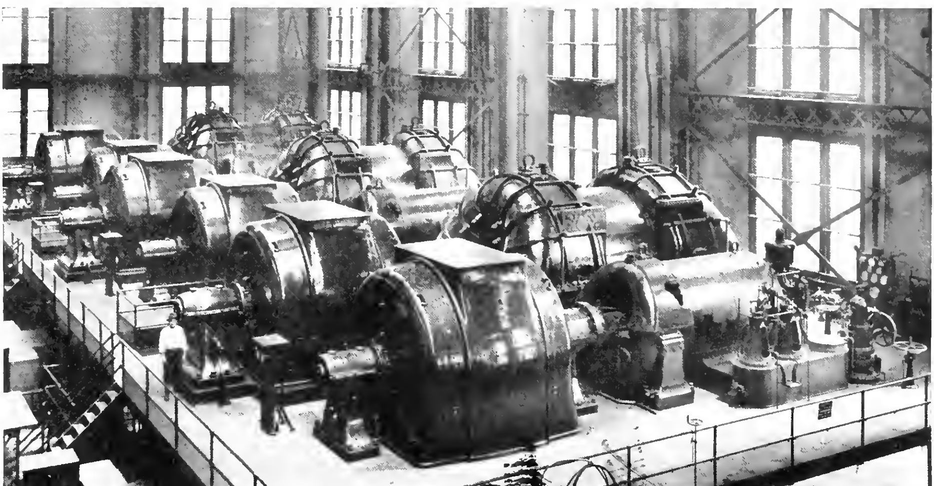

FIG. 1—THREE 30 000 KW TURBINES INSTALLED IN THE SEVENTY-FOURTH STREET POWER STATION OF THE INTERBOROUGH RAPID TRANSIT COMPANY

The generally accepted essential requirements of a railroad plant were the next considerations, viz., reliability, efficiency and cost. In the development of turbine design, at the time the installation was being considered, possibly the simplest type of machine was the single-shaft, single-rotating element turbine as a natural outgrowth of the generally accepted type developed in smaller capacities. Certain structural features, however, inherent with the larger capacity, tended to favor the division of the unit into two elements.

In a steam turbine, maximum centrifugal stresses are encountered at the exhaust end, where the greatest steam volume requires the greatest blade area. In the high-pressure blading which uses steam of small specific

volume, the best velocity ratio conducive to high economy cannot be met by the rotative speed as determined by the exhaust end. To avoid a compromise, the conditions are more readily satisfied by carrying out the expansion in two separate elements, and avoiding congestion due to the high specific volume of the steam at one inch absolute exhaust pressure by the use of the lower speed, longer blades and the double-flow principle. In the matter of efficiency the double unit offered still more desirable possibilities, prominent among which was the relative flatness of its water rate characteristic.

Reliability also seemed better served in the double element machine by the shorter shaft, and reduction of danger from temperature strains. Furthermore, there was the possibility, in an emergency, of operating either element of the unit alone, and that at a fairly high efficiency, the low-pressure element being available for service simply by the use of a bypass. The use of the high-pressure end alone in the case of a bad breakdown on the low-pressure end was to be obtained by removing the low-pressure rotor and closing the shaft openings with special covers.

An extremely important consideration, favoring the divided unit in this particular case, was the matter of the weight of the parts to be handled by the crane which, in the case of the single unit, involved provision for additional crane capacity beyond that then available at the plant. To take care of such additional requirements would have necessitated the installation not only of a new crane, but reinforcements of the steel work of a most elaborate nature and far in excess of that required for use in connection with the double unit.

The group of complete units is shown in Fig. 1, the high-pressure element with its governing apparatus being in the foreground. This element is practically a typical single-cylinder reaction turbine, containing 38 rows of blades. The low-pressure element in the background is a turbine of the double-flow type. Each turbine was erected upon a foundation of steel framework set in concrete, the steel structure alone being amply sufficient for support, the concrete being added to eliminate vibration. Inasmuch as the high-pressure rotor was inherently of small diameter, it was possible to design it to operate at the maximum speed possible for 25 cycle service, i. e., 1500 r.p.m. The low-pressure turbine was designed for the next lower synchronous speed, namely, 750 r.p.m., utilizing a four-pole generator.

The surface condensers which occupy most of the open space beneath the foundation framework consist each of two shells containing 25 000 sq. ft. of condensing surface apiece. The condenser shells are connected directly to the turbine outlets without an intermediate expansion joint. The weight of the condensers is carried by means of lugs, cast as a part of the shell, resting upon a number of spring jacks, which are adjusted to carry the load without appreciable strain upon the turbine exhaust nozzles. Practically no restraint has been put upon longitudinal expansion of the low-pressure turbine by the circulating water piping, which is fitted with rubber expansion joints. There is one expansion joint of copper in the steam equalizing pipe between the shells.

The condenser auxiliaries were selected and installed with the prime factor of reliability continually in mind. The turbine-driven tri-rotor circulating pumps of 37 500 gal. per min. capacity each were installed in duplicate, the reliability consideration being augmented by one of efficiency in the matter of the relative requirements for winter and summer use; during the winter months with cold water one pump is sufficient, but during the summer months high water temperatures necessitate two units. The hot well pumps were also installed in duplicate. A single rotary dry vacuum pump was provided for each unit, with sufficient capacity to handle the dry air from two units, cross connections being provided for the purpose.

The turbines are equipped with water-sealed glands. The gland water system has a small centrifugal turbine-driven pump for each unit, the piping for all of which is cross connected through a common header. The water used for the turbine oil coolers returns the heat which is thus regained by way of the feed water heaters. The return of heat from the oil coolers amounts to nearly one percent of the total heat in the turbine, and the heat in the air from the turbine generators, which amounts to about one percent, is also returned by carrying a discharge duct to the boiler room cellar, where the warm air is used by the forced draft fans.

The exhaust from the auxiliaries has been carried into the feed water heaters, which operate at low pressure. The shortage or excess of heat in this heater system, as the case may be, is compensated for or utilized by means of heat balance valves operating between the auxiliary exhaust lines and the receivers between the turbine elements.

The station in which this apparatus is located was designed about the year 1900, so that from that time until the present represents a period of about sixteen years. This installation illustrates very well the tremendous evolution of the art in that brief period. The engines which were installed at that time consisted of a horizontal, high-pressure cylinder connecting on to a vertical, low-pressure cylinder, at right angles on the same crank pin. Then on the other side of the generator was a duplicate set. Only two cranks were required for four cylinders. These engines established an enviable reputation for reliability. Their economy was as good as could be expected in reciprocating engines at that time, with the comparatively moderate pressure of about 175 lb. and no superheat. The valves were the regular Corliss type.

It is interesting to recall about what these units cost. They were 5000 kw rating, with a maximum overload capacity of 50 percent, bringing up the maximum load to 7500 kw, which they would readily carry, but with correspondingly poor water rates. The water rate of the engine on test ran over 17 lb. per kw-hr., and that was considered a very good record. The cost of these units,

for the engine, generator and condenser, was a little over $40 per kw capacity, based on the rated capacity.

The original plant was designed on what was practically a unit basis, as far as the engines and boilers are concerned, that is to say, there was a group of eight 520 hp boilers per unit, and each unit could be operated independently of the rest of the plant, but normally was operated with all the boilers connected together through two headers. The boiler capacity therefore, was 4160 boiler hp for a 5000 kw unit.

In place of the engine there was installed a 30 000 kw cross-compound unit, and that unit of 30 000 kw capacity was placed between the same centers as the 5000 kw unit taken out. The cost per kilowatt of the modern unit, including condensers, was a little over $9, as compared with $40, in the first place. The new unit is operated by the same eight boilers, that is, the boiler capacity has not been increased, except to put in underfeed stokers under the boilers, so that we have simply changed a 5000 kw unit to a 30 000 kw unit. That is about six to one increase in capacity, on the same number of boilers.

The improved water rate is obtained through the more economical turbine and through the use of superheat, so that the actual water rate, discounting the superheat, is, with the present unit on the average of about 12 lbs., as compared to about 17.5 on the average with the previous unit.

The advantages which have been procured are, first, in the same floor space is installed six times the capacity at a cost per kilowatt of approximately one-fifth of the original unit; and the water rate, when reduced to saturated steam, has been reduced approximately fifty percent, an enormous gain.

The progress of the steam turbine has been so great that today it has practically displaced the gas engine. The thermal efficiency given in the test runs up to about 25 percent. That is practically in the same class as the best gas engine practice today. So, as the cost of the gas engine unit is probably seven or eight times as great as the turbine unit, the gas engine has been practically put out of the running for large power plant work.

Another very interesting sidelight is the value of the installation as a general prime mover in competition with anything else that could be cited. Fifteen years ago hydroelectric power developments were looked on as a choice investment, worth lots of money at almost any cost of development. Water-powers were developed that cost $200, $250 and $300 a kilowatt. Today money could not be obtained for an investment of that kind, simply because the steam turbine has become so efficient and at the same time decreased in first cost that it has driven out all possibility of developing a great many of these water-powers, because, considering the fixed charges, the steam turbine can make power more cheaply than the high-priced hydroelectric development.

TABLE I—SWINGING LOADS DURING TESTS AS RECORDED BY GRAPHIC CHART

		Average	From Graphic Load Chart									
Test No.	Duration of Test Hours	Kw. Load by Watthour Meter A	Minimum Load During Test B	Maximum Load During Test C	Difference in Kw. of Max. and Min. Loads C—B=D	Percent of Avg. Load D/A	Avg. of Dif. Bet. Min. and Max. Load During Each 2½ Min. Period During Test, E	Percent of Avg. Load E/A	Max Single Load Swing During Test F	Percent of Avg. Load F/A	Length of Swing F in Sec.	Time of Test
1	3	16342	10100	20800	10700	65.5	6080	37.2	8700	53.3	21	12.00—3.00
4	3	18273	10400	23100	12700	69.5	5860	58.0	10600	58.0	41	12.00—3.00
6	3	20472	15600	22600	7000	34.2	3810	18.6	6500	31.8	42	2.00—5.00
8	3	22150	16500	27400	10900	49.2	4200	19.0	6500	29.4	24	8.00—11.00
11	3	24200	20500	27600	7100	29.3	3160	13.1	4300	17.8	15	8.00—11.00
13	3	26153	20200	28900	8700	33.3	3080	11.8	5400	20.6	12	8.00—11.00
15	3	28378	21000	32700	11700	41.2	3700	13.0	5400	19.0	1	3.30—6.30
17	3	30232	24400	32000	7600	25.1	3040	10.1	4500	14.9	12	3.30—6.30
20	3	32348	32900	28300	4600	14.2	2400	7.7	3100	9.6	5	1.00—7.00

TABLE II—SUMMARY OF RESULTS, NINE TYPICAL TURBINE TESTS FROM A TOTAL OF TWENTY-FIVE

	Abs. Steam Pressure at Throttle	Steam Temperature at Throttle	Superheat	Abs. Steam Pressure Primary Inlet	Abs. Steam Pressure Exhaust H.P.	Abs. Steam Pressure Inlet L.P.	Exhaust Vacuum	Exh. Pres. Referred to 30-In. Bar, 58.1 Deg. F.	Load Average	Water per Hour	Water* Rate	Rankine* Cycle Efficiency	Thermal* Efficiency
Test No.	Lb. per Sq. In	Deg. Fahr.	Deg. Fahr.	Lb. per Sq In.	Lb. per Sq In.	Lb. per Sq In	In. Hg.	In. Hg.	Kw.	Lb.	Lb. per Kw.-Hr	Percent	Percent
1	224.3	493.2	101.6	148	10.6	10.2	28.411	1.580	16 342	192 350	11.770	72.540	23.72
4	223.3	489.6	98.4	159	11.8	11.5	28.471	1.529	18 273	212 330	11.620	73.476	24.02
6	220.4	510.0	121.0	175	12.7	12.0	28.586	1.414	20 472	234 930	11.476	74.400	24.33
8	221.8	518.8	128.0	185	13.5	12.8	28.791	1.209	22 150	253 388	11.439	74.030	24.41
11	220.3	512.9	123.0	196	13.7	13.6	28.882	1.118	24 200	275 593	11.388	74.973	24.32
13	217.9	524.3	135.2	211	14.5	14.7	28.761	1.239	26 153	295 373	11.294	75.597	24.72
15	221.6	510.0	119.5	210	16.5	15.9	28.862	1.138	28 378	323 353	11.395	74.928	24.51
17	220.3	513.0	123.0	210	16.5	16.8	28.78	1.22	30 232	344 787	11.405	74.862	24.48
20	218.2	519.5	130.4	209	17.6	18.2	28.75	1.25	32 348	366 572	11.332	75.343	24.64

*As corrected to 215 lb. per sq. in. absolute pressure, 120 deg. F., superheat; 29 in. mercury.

TEST RESULTS

For test purposes one unit was selected as representative of the installation. Tests were made upon this unit by the use of standard methods, special provisions

being made to secure accuracy, some of which are retailed below:—

High steam pressures were observed by the use of gages, in duplicate where of importance, such gages being calibrated before and after each test. Temperatures were observed by calibrated thermometers, immersed in iron pipe wells, filled with mercury or oil,

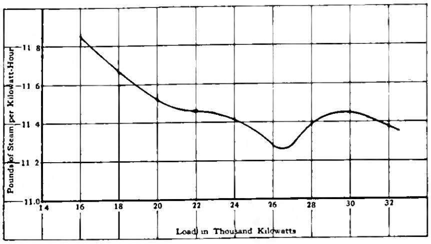

FIG. 2—WATER RATE CURVE

depending upon conditions. Wells were of ample depth and correction was made for immersion. Low pressures were observed by the use of mercury manometers. Vacuum readings were made by the use of mercury columns provided with a vernier reading of 1/100 of an inch. The mercury in these columns was regularly cleaned and its specific gravity determined before and after test series and corrections made accordingly. Temperature corrections on mercury columns were provided for by the use of thermometers set in each column casing and additional corrections were made for specific gravity, meniscus and barometer reading. The barometer used on the test was calibrated by reference to the U. S. Weather Bureau.

The condensate was weighed in tanks mounted upon two carefully calibrated platform scales. Platform scales were also used to measure drips and leakage. The

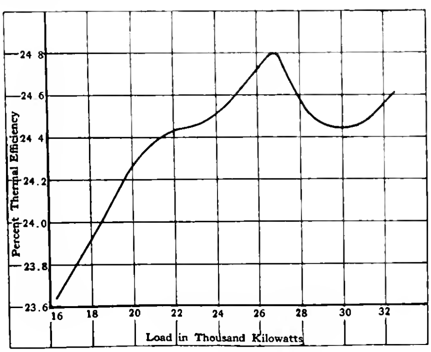

FIG. 3—THERMAL EFFICIENCY CURVE

unit was isolated so far as water and steam outlets were concerned. The large atmospheric relief valve necessarily remaining connected to the exhaust system was water sealed, the seal being kept under continual observation by means of a window in the valve cover and interior illumination by electric light.

The unit output was obtained by means of three single-phase rotating standard watthour meters, one connected to each phase. These watthour meters were calibrated before and after the test series, which calibration included the current and potential transformers and showed no variation in excess of 0.2 percent.

Each test was of three hours' duration, with about a half-hour preliminary operation under test conditions. The load was controlled from the switchboard, the turbine operating upon the governor with hand throttle wide open. This subjected the turbine to the full swings of the railroad load, as observed by a graphic wattmeter. Table I gives a summary of the results. At light loads these variations were more pronounced, approximating frequently 5000 kw either side of the average. A variation of 10 000 kw total in half a minute was not uncommon, especially on loads of 16 000, 18 000 and 20 000 kilowatts, all of which one would suppose would affect the test results quite deleteriously. For while the heat absorbed by the turbine walls during an upward swing is all given back to the steam in a downward swing the heat is taken from the steam when it is

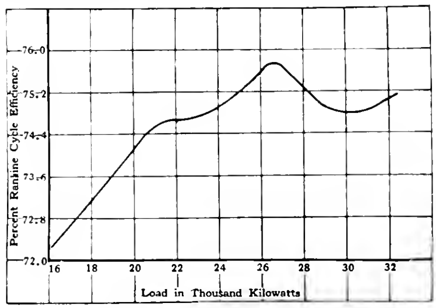

FIG. 4—RANKINE CYCLE EFFICIENCY CURVE

at a higher pressure than when it is returned to it, which is, of course, a direct loss. However, subsequent tests with the governor hobbled did not show any particular difference.

The test results have been shown graphically in Figs. 2, 3 and 4, upon bases of load and water-rate, load and thermal efficiency, and load and Rankine cycle efficiency ratio. In conducting these tests, naturally every effort was made to maintain certain standard conditions under which guarantees had been given, and the test results as tabulated have been corrected to such standards. These standards represent what is probably the average of operating service. Corrections for variation from standard conditions were based upon curves which were agreed upon prior to the commencement of tests.

In discussing and analyzing the test results, attention might be called to the following particular features:—

1—With due allowance for scale of ordinates the performance curves may be considered unusually flat, naturally conducive to high plant efficiency.

2—The dip in the curve between 22 000 and 26 000 kw is a peculiarity which was received at first rather skeptically, but which was later remarkably checked by repetition of tests throughout the range, including a special series under steady

load made three months subsequent to the original series. Various theories have been advanced in connection with this dip, and a series of special tests was made to investigate the relative action of the receiver between the two cylinders as a separator, and the velocities of the steam passing through it, with the idea that this might have some direct bearing upon this dip. Unfortunately, winter load demands terminated further research work in this direction without any definite results having been obtained.

3—The turning up of the curve between 30 000 and 32 000 kw is another peculiarity, accounted for by the turbine designer as follows:—

"Concerning the turning up of the efficiency curve between 30 000 and 32 000 kw, consideration and calculation indicate that this is actually not an inconsistency, but a new experience. This turbine was designed for higher hydraulic efficiency than probably any machine heretofore built, thus approaching the crest of the efficiency curve. The overload capacity of the machine is small, or in other words, the amount the turbine is by-passed when the secondary valve opens is small, and the velocity ratio, therefore, is very little lower when full steam pressure is applied to the secondary inlet than when such pressure is applied to the primary inlet. Further, the hydraulic efficiency is nearly the same, so that the Rankine cycle at 32 000 kw should not be more than one percent lower than at the point of best efficiency, viz., 26 000 kw. The efficiency at the intermediate overload, say, 30 000 kw, is somewhat worse than this, for while the blading and hydraulic efficiencies remain as high there is a loss due to a certain portion of the steam expanding through the secondary valve to a lower pressure without doing work."

A number of tests were made upon the condensers and auxiliaries, separate and individual guarantees having been made upon the condenser proper, circulating pumps, dry vacuum pumps and hot well pumps. Publication of this test data would simply show good efficient performance without unusual features.

The coal per kw-hr. on the engines before the turbines were put in at all was about 2.5 lb. of coal for the plant, averaged at the end of each month. That included, of course, everything, all auxiliaries, coal-handling apparatus, and everything else. Since the turbines were put in, and while they have been carrying practically all of the load, with the steam mains leading to the engines still alive for emergency purposes, the coal consumption is approximately 1.5 lb., a drop of one lb. per kw, as the result of the installation of the big turbines. The thermal efficiency of the station for the monthly average is approximately 17 percent.

Summarizing the results of these tests, it may be said that the performance in the case of both turbine and condenser showed higher efficiencies than was guaranteed under contract, and the installation has proven to be thoroughly satisfactory in every particular, having fully realized the considerations which governed its selection.

The Use of Protective Relays on Alternating-Current Systems

L. N. Crichton

RELAYS for protecting apparatus and for disconnecting disabled sections of transmission lines have become indispensable, and the growth of distribution systems has called for the development of relays that are particularly accurate and reliable. By the use of such relays automatic sectionalizing can be applied to distribution systems which a few years ago were considered too complex for such applications. In applying relays it is necessary to consider the innumerable operating problems which are more or less distinctive of every system, and to pay particular attention to the characteristics of the relays, circuit breakers, generators, transformers, lines and motors. These variables require careful study on the part of the operator.

As an example of the service possible from a correctly designed system of sectionalizing relays may be cited the case of a long-distance transmission company supplying power to an important industry which a few years ago suffered more than 25 interruptions annually. A systematic study of the sectionalizing problem was made, which resulted in a comparatively small expenditure for relays and a slight rearrangement of switching apparatus. As a reward for this work the service to the important customers on the system is now almost perfect, and the company officials expect in the future not more than one interruption annually from all causes. This system contains more than 1400 miles of transmission line and suffers not less than 100 short-circuits and grounds per year; nevertheless, the chance for an extensive interruption from line trouble is now much less than from an accident in a generating station.

Such service frequently pays for itself in a conspicuous way, as in the case of a hydroelectric system which for years had maintained an auxiliary steam plant on a hot stand-by basis. As the result of the installation of a complete automatic sectionalizing scheme it was found possible to place this plant on a cold stand-by basis, thus effecting a large saving.

Another direct financial benefit from a relay installation is the saving in copper which results from the use of a closely inter-connected system. Sometimes a power customer demands a separate set of feeders from the generating station, in order that his service may not be disturbed by troubles on the remainder of the system. Such practice requires an uneconomical amount of copper because the diversity factor of the system cannot be utilized. A proper equipment of relays will allow the use of tie lines and of other inter-connections, with the result that more load can be carried and the service to each customer will be improved because more sources of power will be available.

The object of protective relays is to secure continuity of service, and this applies whether the relays are installed so as to disconnect defective sections of line or to disconnect apparatus which is in danger of causing trouble or which has already become a source of disturbance. Although the apparatus and methods used are continually permitting more reliable service, at the same

time electrical systems are increasing in size, with a resulting increase in causes and chances for disturbance. It is, therefore, necessary to install sectionalizing devices before perfect service can be secured.

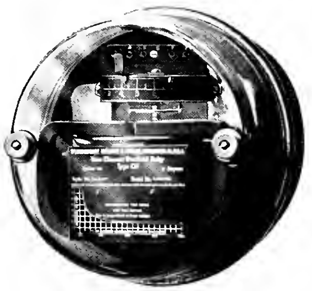

FIG. 1—ADJUSTABLE DEFINITE MINIMUM INVERSE TIME ELEMENT OVERLOAD RELAY
Westinghouse Type CO.

SECTIONALIZING OF TRANSMISSION LINES

The following discussion will be limited to the application of relays to three-phase systems, because such systems offer peculiar difficulties and because they are almost exclusively used for transmission purposes.

Interruptions may be defined as any disturbances which will cause a loaded induction motor to stop. The disturbance which a motor can withstand depends upon the nature of the load and the characteristics of the motor, but it may be safely stated that any motor can have the voltage at its terminals reduced to zero for at

FIG. 2—ADJUSTABLE DEFINITE MINIMUM INVERSE TIME ELEMENT REVERSE POWER RELAY
Westinghouse Type CR.

least two seconds without "interrupting" it. The only method of handling disturbances which will be considered will be the method of automatically disconnecting any section of line or piece of apparatus which is creating trouble; other methods of clearing disturbances without disconnecting the lines, such as the use of arc suppressors and voltage-killing devices, being outside the scope of this discussion. It should be further realized that existing types of relays cannot clear grounds unless they amount to short-circuits, as in the case of a

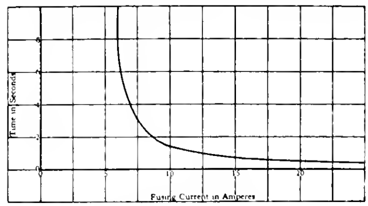

FIG. 3—TIME CHARACTERISTIC OF A FUSE
Consisting of a three-inch length, No. 32, B & S gage copper wire.

grounded neutral system. A ground on an isolated neutral system will not ordinarily cause an interruption unless it should develop into a short-circuit, in which case sectionalizing relays will operate.

Fuses are in quite general use for protective purposes and are invaluable for some applications because of their quick action when a short-circuit occurs, a feature which is particularly important on high-voltage systems where the current to be handled is small and the large circuit breakers which would otherwise be used are slow in operation. The characteristic action of a copper wire fuse is shown in Fig. 3.

Circuit-Breaker Characteristics—The small circuit breaker which is equipped with an instantaneous overload trip coil can be made to operate very rapidly; the trip coil itself will release the latch in less than one cycle when a heavy short-circuit occurs. The time required

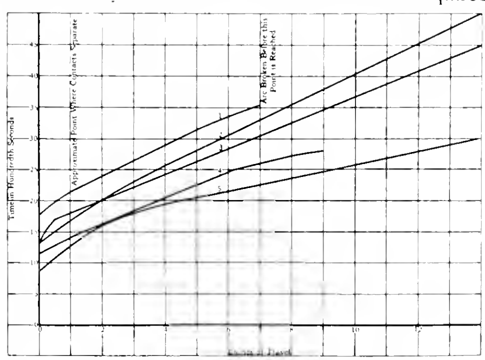

FIG. 4—TYPICAL TIME CHARACTERISTICS OF OIL-CIRCUIT BREAKERS
Showing time of opening contacts with various types.
1—15 000 volts, 2000 amperes. 2—88 000 volts, 300 amperes.
3—66 000 volts, 300 amperes.

for a circuit breaker to open the circuit depends, of course, upon its size and the inertia of its moving parts, but for large capacity motor-operated or solenoid-operated circuit breakers having a rating of 15 000 volts or less it is between 0.2 and 0.3 seconds. The curves in Fig. 4 show the characteristics of such circuit breakers, although they may be altered materially if the operating

voltage is low or the spring adjustment and other mechanical features are changed. Most of the time is consumed in energizing the trip coil and in overcoming the inertia of the moving parts, so that a 150 000 volt circuit breaker having a longer contact travel should not require much greater time to operate than is required by a low-voltage breaker.

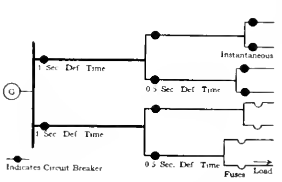

FIG. 5—RADIAL DISTRIBUTION SYSTEM

Single Source of Power—Radial Distribution System—The method of applying time-limit relays will first be considered for a distribution system having only one source of power supply. Fig. 5 shows a radial system, which consists of a number of feeders leaving the generator bus-bars, each feeder being in turn sub-divided into a number of smaller feeders. The smallest branches may be automatically disconnected from the remainder of the system by the blowing of fuses or the operation of instantaneous circuit breakers. The circuit breakers nearer the generator station are equipped with definite time-limit relays, the time interval between the successive relays being enough to insure a reasonable margin of safety above that required for the circuit breakers to operate. If, in addition to the variation in the operating of the switches, there is also an uncertainty in the operation of the relays, this time interval will become excessive, which emphasizes the importance of accurate relays. In addition to securing discrimination on the part of the relays by means of a definite time feature, it is also possible to discriminate by the current setting, because trouble which occurs at the far end of

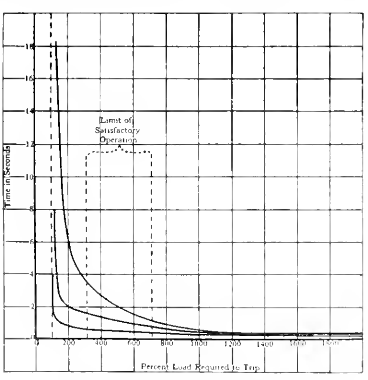

FIG. 6—TIME CHARACTERISTICS OF BELLOWS OVERLOAD RELAY WITH INVERSE-TIME LIMIT

one of the branch lines will not draw as heavy a current as though it were near the generating station. There is also a possibility of securing selective action by using an inverse-time-limit relay having a characteristic curve similar to that shown in Fig. 6. If the calculations are carefully made this relay will operate properly and its use will enable heavy short-circuits close to the generator to be cleared sooner than they could be by the use of definite-time relays.

When the inverse-time and the definite-time relay are combined so that they have the characteristic curve

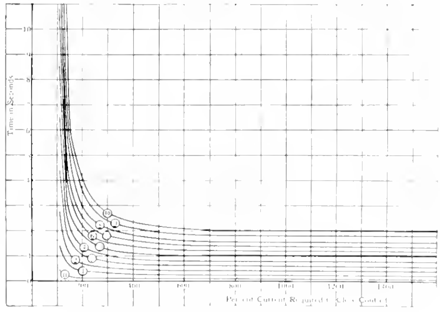

FIG. 7—TIME CURVES OF TYPE CO RELAY
Numerals on curves indicate time setting.

shown in Fig. 7, the combination is well adapted to this service, because either the inverse-time part of the curve or the definite-time part can be used, depending upon the particular circumstances.

Parallel Feeders—Another simple arrangement of feeders is shown in Fig. 8 which illustrates a single generating station and substation connected by a number of parallel circuits. It has been frequently stated that such a system can be protected by the use of inverse-time-limit relays at the end of each feeder, and the success of these relays is supposed to be due to the fact that the particular circuit which is in trouble will draw a much heavier current than do its neighbors, with the result that the relay on the defective circuit will operate first. Experience has shown that this arrangement will not always operate properly. It will be seen by inspection of Fig. 6 that the inverse-time-limit relay can be depended upon only between the limits of the two dotted lines. For greater current values it will not discriminate, because it is practically instantaneous, and for smaller values it requires such a long time to operate that a serious interruption would occur

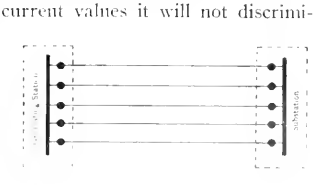

FIG. 8—PARALLEL FEEDERS

before a defective line could be disconnected. The result of such a limited range is that the relays cannot be adjusted to take care of all conditions when the connected generator capacity is changed. For instance, on a system having a load factor of 40 percent, which is not unusual, the connected generator capacity at full load may be at least three times as great as the connected capacity at light load. Furthermore, the setting of inverse-time-limit relays is made difficult by the short-circuit characteristics of the generators. In Fig. 9 is shown how rapidly the short-circuit current of a generator de-

creases, and also shows how difficult it would be to approximate the effective values of this current when setting relays. Inverse-time-limit relays are thus shown to be impractical for protecting parallel feeders.

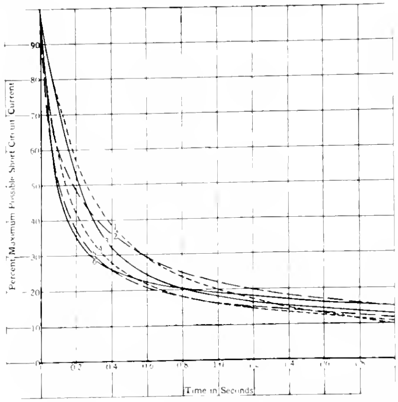

FIG. 9—CURRENT DECREASE ON UNSYMMETRICAL SHORT-CIRCUITS

				R.P.M.	Cycles	Phases Shorted
1	15 800	K.v.a	Turbo	1500	25	3
2	20 000	K.v.a	Turbo	1800	60	1
5	19 000	K.v.a	Turbo	1875	62.5	1
3	12 000	K.v.a.	Alternator	116	25	3
4	6 600	K.v.a.	Alternator	375	25	3
6	15 000	K.v.a.	Alternator	375	50	3

The proper way to protect service against trouble on parallel feeders is to place reverse-power relays at the substation end of each feeder, and definite-time-limit relays at the generator end, as shown in Fig. 10. This figure shows a system consisting of a combination of parallel and radial feeders. Such a system may be simplified until it includes nothing but a generating station and a substation with two feeders connecting them.

Ring System—The ring system shown in Fig. 11 is similar to the case of two parallel feeders supplying a substation, except that each feeder is made to loop through a number of substations. On such a system definite-time-limit reverse-power relays must be used, and the time limit of each successive relay should be increased by a sufficient amount to allow time for the circuit-breaker in the preceding substation to open. In the illustration it has been assumed that one-third second

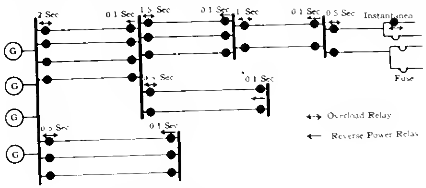

FIG. 10—USE OF REVERSE POWER AND DEFINITE-TIME LIMIT RELAYS ON PARALLEL FEEDERS

is a sufficient time to allow for this purpose, but such a small setting cannot be used unless the relays are accurate.

Systems Having More Than One Source of Power—such as the system shown in Fig. 11 would be if a generator were placed at substation *D*. One difficulty would be encountered if the generator at *A* should be shut down and all the load carried by the generator at *D*. In this case the entire relay system would have to be readjusted, as shown in Fig. 12. Although this example is a simple one, it illustrates the condition which occurs whenever a complicated system of distribution is en-

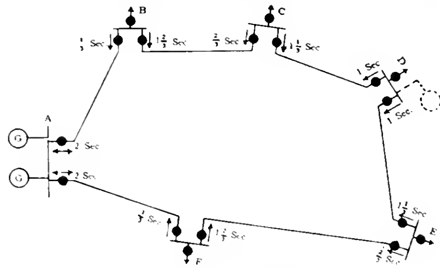

FIG. 11—RING SYSTEM

countered. It also illustrates the necessity for using relays whose adjustment can be quickly changed.

Parallel Feeders—When parallel feeders are used, reverse-power relays interconnected, as shown in Fig. 13, will give satisfactory service, irrespective of the direction of the normal flow of power. In this method the current transformers on the same phase of all the feeders are connected in series and each relay is shunted across its transformer. It is obvious that when the feeders are in good condition the current through the current transformers will be in the same direction in all of them and, as a result, very little current will flow through the individual relays because of their impedance. When one of the feeders fails, the current in it will be in the reverse direction to that of the others, or it will be much larger; in either case it will cause current to flow through the relay in the proper direction to trip the circuit breaker. The scheme must be used with caution because of the trouble which might occur if the current transformer leads have too much inductance or if the current transformer ratios are not adjusted to suit any difference which may exist in the impedance of the

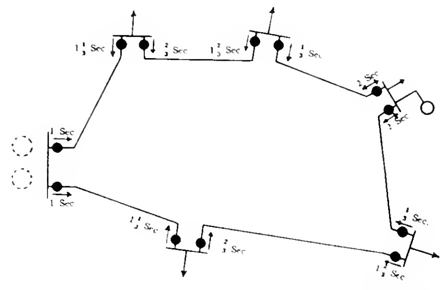

FIG. 12—RING SYSTEM HAVING MORE THAN ONE SOURCE OF POWER

various cables. It is evident that if all the cables are not alike it will be necessary to correct for their dissimilarity by using current transformers having different ratios. When one of the feeders is disconnected it is necessary to short-circuit its current transformers, which can readily be done by placing a small pallet

switch on the circuit breaker. This should be done even when there are only two lines, in which case a line will be non-automatic if it is the only one left in service. This scheme will fail upon occurrence of trouble which short-circuits one end of a feeder and leaves the other end clear. These objections are of slight consequence, and this scheme is the only one which can be satisfactorily used without requiring pilot wires, split conductors, or similar devices.

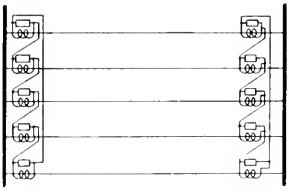

FIG. 13—PROTECTION OF PARALLEL TIE LINES

Networks—The method just explained can also be applied to sections of a network such as is shown in Fig. 14. The difficulties which will be met with in protecting the duplicate feeders have already been considered and, for purpose of illustration, several other connections have been shown, although it is not to be assumed that these few examples cover all the problems which will arise in practice. In case of trouble, it is not always possible to prevent automatic switches from operating when the feeder which they control is not affected, nor is there any objection to opening a few such circuit breakers if they will not cause an interruption to part of the load. It frequently happens that the problem of automatic sectionalizing can be very much simplified if, at the first instant of short-circuit, a number of circuit breakers are opened for the purpose of simplifying the operation of the remainder of the system. In Fig. 14, for instance, is shown a feeder between substations *N* and *S*, which normally assists in maintaining voltage regulation, but which could be dispensed with for a time if there should be trouble on the line. We have, therefore, assumed that the circuit breaker on section *A* in the substation *N* is equipped with an instantaneous relay. If it should happen that the trouble is on this section of line, the relay in substation *S* will operate after one-half second, and clear the trouble; but if the trouble is not on this particular feeder no harm will be done and the load which is supplied from it will not be interrupted. In order that synchronizing and other switching on the system will not cause interruptions, it is assumed that the minimum time limit of one-quarter second is necessary. If such a setting is used, and a short-circuit occurs at the point *Z*, the relay in substation *N* will require one-quarter second to operate, and there will be a further one-quarter second required for the circuit breaker to open. The relays at substation *P* will not begin to operate until the switch at substation *N* has opened, because it is assumed that the short-circuit is close to the latter substation and there is, consequently, no unbalancing at substation *P*. There will, therefore, be still further delay of one-half second at substation *P* before the trouble is finally cleared. It is for this reason that the definite time limits in the tie feeders between substations *P*, *S* and *T* have been shown to be higher than appears necessary at first sight. With the setting shown in these substations it will require more than two seconds to clear a case of trouble should it occur in either section *B* or *C*. For this reason it may be thought advisable to adjust the relays at substation *T* so that they have a lower time setting, with the result that one of them will operate on practically all cases of trouble, but, as in the case of section *A*, this will not result in any interruption of service; it will merely trip out a circuit breaker which can later be closed by the attendant.

These illustrations show how to adapt relays to complicated systems, thus securing all the advantages which can be obtained from a close interconnection of stations and substations.

Pilot-Wire and Split-Conductor Schemes—A number of years ago a pilot-wire scheme was proposed which operated from secondaries of current transformers placed at the two ends of a feeder and which, consequently, required that a number of conductors be run between the substations. For cable systems it is said to give satisfactory results, but for long-distance transmission lines it is not reliable. It ordinarily makes use of standard overload relays. The use of split conductors has been applied more recently, apparently with good results. This scheme is applicable only to cable systems, and consists in splitting each conductor into two parts, and using a relay which operates whenever the current in the two halves becomes unbalanced. A three-phase cable constructed on this plan contains six conductors instead of three, which not only increases the cost of the cable, but increases its size, thus requiring more investment in duct space. Although both the pilot-wire and the split-conductor schemes are reported to give satisfaction, there seem to be a number of conditions where failure is possible, and it does not appear that they can be any more reliable than the other schemes described.

CALCULATION OF SHORT-CIRCUIT CURRENT

In applying any protective scheme it is necessary to determine the short-circuit currents which will be available under all conditions.

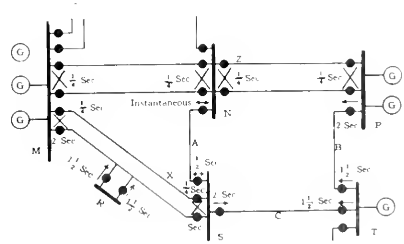

FIG. 14—NETWORK DISTRIBUTING SYSTEM

It is unfortunate that the term "overload" has ever come into use in connection with sectionalizing distribution systems, because it implies that the relays should be set to operate at a value determined by the normal load on the feeder. Such a

setting is possible if definite-time-limit relays are used, but where a relay having inverse-time characteristics is used it is necessary to consider the current which occurs during times of trouble, and which may be tens or even hundreds of times greater than the normal current. An approximate method of determining the possible short-circuit current is by observing the voltage drop between two stations at normal load.

$$\textit{Short-circuit current} = \frac{\textit{normal voltage}}{\textit{voltage drop}} \times \textit{load current.}$$

For example, if a certain load current causes a drop of five percent in voltage between a generating station and substation, the maximum short-circuit current would be 20 times the load current. Results obtained in this way are likely to be too large, particularly on lines having high inductance.

TABLE I—RESISTANCE, INDUCTANCE AND IMPEDANCE OF OVERHEAD LINES

Resistance (R)		Inductance X and Impedance Z per wire per mile.							
Spacing—Ft.		2		4		8		15	
Size Wire	R	X	Z	X	Z	X	Z	X	Z
				25 CYCLES.					
0000	0.267	0.245	0.365	0.280	0.387	0.315	0.413	0.348	0.437
000	0.336	0.251	0.420	0.286	0.442	0.320	0.463	0.352	0.487
00	0.423	0.257	0.495	0.291	0.563	0.326	0.535	0.358	0.553
0	0.534	0.262	0.595	0.297	0.611	0.332	0.628	0.364	0.647
2	0.849	0.277	0.895	0.312	0.905	0.347	0.917	0.378	0.930
4	1.35	0.288	1.38	0.324	1.39	0.358	1.396	0.390	1.40
6	2.15	....	....	....	....	....	....	0.401	2.10
8	3.400	....	....	....	....	....	....	0.413	3.43
				60 CYCLES.					
0000	0.267	0.587	0.645	0.672	0.723	0.755	0.801	0.831	0.873
000	0.336	0.601	0.690	0.685	0.763	0.769	0.839	0.845	0.908
00	0.423	0.615	0.745	0.699	0.815	0.782	0.888	0.859	0.958
0	0.534	0.620	0.825	0.714	0.802	0.797	0.958	0.873	1.03
2	0.849	0.664	1.075	0.748	1.130	0.832	1.188	0.908	1.23
4	1.35	0.692	1.515	0.776	1.555	0.860	1.60	0.936	1.64
6	2.15	....	....	....	....	....	....	0.964	2.35
8	3.40	....	....	....	....	....	....	0.992	3.54

Above values are to be used with voltage to neutral. Sizes No. 0000 to 0 are stranded: others are solid. Based on 97 per cent conductivity at 20 degrees C. or 67 degrees F. Values in Table computed on slide rule.

TABLE II—APPROXIMATE OHMIC RESISTANCE AND IMPEDANCE THREE CONDUCTOR CABLES, AT 60 CYCLES

Size	Resistance Ohms per Mile	Impedance Ohms per Mile. Working Voltage.					
		3000	5000	7000	10000	15000	20000
2	0.850	0.858	0.859	0.863	0.867	0.872	0.884
1	0.674	0.692	0.696	0.700	0.706	0.712	0.724
0	0.535	0.545	0.547	0.552	0.558	0.565	0.580
00	0.424	0.436	0.439	0.444	0.452	0.460	0.478
000	0.336	0.352	0.352	0.357	0.365	0.374	0.396
0000	0.267	0.280	0.283	0.288	0.296	0.306	0.332
250000	0.227	0.245	0.245	0.252	0.261	0.272	0.299
300000	0.188	0.210	0.210	0.217	0.227	0.241	0.270
350000	0.161	0.187	0.187	0.194	0.204	0.217	0.250
400000	0.141	0.166	0.166	0.174	0.185	0.199	0.234
450000	0.127	0.148	0.148	0.156	0.167	0.182	0.221
500000	0.113	0.137	0.137	0.144	0.156	0.172	0.212

Based on Pure Copper, 75° F. with an allowance of three percent for spiral path of conductors, 60 cycles per second and standard thickness of varnished cambric insulation. Values are practically the same for other types of insulation. These figures are also approximately correct for 98 percent conductivity copper at 65° F.

The calculation of the short-circuit currents on a complicated system involves more or less approximation, and a good method is to prepare a table showing the impedance of each section of line and also of the generators. These figures can then be combined in any way desired to determine the impedance of a particular path. In obtaining the impedance of several sections of a system, the resistances and inductances must be added separately and the two sums combined geometrically. The inductance varies with the size of the conductors and with the distance between them, which in the case of a cable is determined by the thickness of the insulation. The characteristics of cables can usually be obtained from the manufacturers. A 15 000 volt No. 0000 cable at 60 cycles has an impedance about 23 percent greater than its ohmic resistance, whereas the impedance of a 150 000 volt line having the same size copper conductors spaced 15 feet apart is about three and one-quarter times the value of its resistance. The resistance, inductance and impedance of aerial transmission lines having various wire spacings is given in Table I, and Table II shows the resistance and impedance of various kinds of three-conductor cable.

The method of computing the impedance of a circuit, including a line, generator and transformer, is shown in the following example:—

Assume:—A 5000 k.v.a., 60 cycle generator having 10 percent reactance drop.
A 5000 k.v.a. bank of transformers having one percent resistance drop and five percent reactance drop.
50 miles 45 000 volt line No. 0 copper conductors spaced four feet apart.

All values of resistance, reactance and impedance will be reduced to terms of 45 000 volts.

$$\text{Full load current} = \frac{5\,000\,000}{\sqrt{3} \times 45\,000} = 64 \text{ amperes.}$$

Star voltage = 26 100.

Generator Characteristics:—

Reactance drop = 10 percent of 26 100 = 2610 volts.

$$\text{Reactance} = \frac{2610}{64} = 41 \text{ ohms.}$$

Transformer Characteristics:—

Resistance drop = one percent of 26 100 = 261 volts.

$$\text{Resistance} = \frac{261}{64} = 4.1 \text{ ohms.}$$

Reactance drop = five percent of 26 100 = 1305 volts.

$$\text{Reactance} = \frac{1305}{64} = 20 \text{ ohms.}$$

Line Characteristics (from Table I):—

R = 50 × 0.534 = 26.7 X = 50 × 0.714 = 35.7

Summary:—	R	X
Generator	Negligible	41.
Transformer	4.1	20.
Line	26.7	35.7
Total	30.8	96.7 ohms.

$R^2 = 950$
$X^2 = 9150$

$Z^2 = R^2 + X^2 = 10\,100$ Hence Z = 100.5 ohms.

The short-circuit current is therefore $\frac{26\,100}{100.5} = 260$ amperes *for the first instant.* As shown in Fig. 9, the initial current will decrease until the sustained value is reached. In this example the sustained value is probably about twice full-load current, or say 130 amperes. If the line should have more impedance, or if less generating capacity should be connected to the bus-bars, the generator reaction would have less effect in cutting down the current, and the calculated results would need less correction.

Alternator and Transformer Constants—The characteristics of alternators vary through a wide range, but it is usually assumed that their reactance is about eight percent, which allows a maximum instantaneous short-

circuit current of 12.5 times full load. The maximum sustained short-circuit current is usually assumed to be between 2.5 and 3 times full-load, although some machines, particularly turbo-alternators, are now being built which have a sustained short-circuit current of about 1.5 times full load. It is usually safe to assume that a transformer has one percent resistance drop and five percent reactance drop.

Nature of Short-Circuits — When making current calculations it should always be assumed that a short-circuit is due to a metallic connection between the conductors. On a high-voltage aerial line using wooden pins and cross-arms it sometimes happens that an insulator is broken, with the result that the wood is gradually heated by the passage of the current through it until it finally bursts into flame, thus causing an arc between conductors. A little consideration shows that the flow of current is small until the arc is established, and that it is absurd to speak of automatically disconnecting a section of line which has such a high-resistance short-circuit. It has sometimes been assumed that an arc has a high resistance, but this is not the case, and in general the presence of an arc at the point of short-circuit will not decrease the short-circuit current by more than a few percent. Incidentally, it may be of interest to note that on a high-voltage, ungrounded-neutral system the capacity current to ground through an arc is greater than it is through a direct ground. There is only one case where a short-circuit is likely to increase in intensity as it develops, and that is on a system where the neutral is grounded through a resistance; a cable breakdown, for instance, frequently occurs first between one conductor and the sheath and the current flow may be limited by the neutral resistance; the trouble will quickly involve all the conductors in the cable, resulting in a heavy short-circuit, but it is possible that it will require an appreciable time to do this, in which case the relay operation may be unsatisfactory. This is particularly liable to happen if the neutral is not grounded at every substation.

RELAY ACCURACY

A study of the preceding discussion will show the necessity for the use of relays which are not only accurate and constant in their characteristics, but can also be adjusted to operate on small differences of time. The relays shown in Figs. 1 and 2 are individually adjusted and the calibration curve is marked on the nameplate. As a result it is possible to set the relay to the desired value with only a few minutes work. The relay, having combined definite and inverse-time characteristics, is particularly valuable on large systems where constant changing of the connections necessitates frequent changes in the relay settings.

Effect of Low Voltage—The most important requirements of a reverse-power relay is that it should operate when the potential at its terminals is between one and two percent of normal. If we assume the case of a No. 0000 cable normally carrying 300 amperes at 12 000 volts, connected to a generating station having a short-circuit current of 3000 amperes, the loss which would occur between the bus-bars and a metallic short-circuit 100 feet from them would be 45 kw per phase, or less than three-quarters of one percent of the relay setting. This shows the absurdity of installing relays which require a percentage reversal of five or ten percent to operate them. The proper way to construct a reverse-energy relay is to use two elements, one of them an excess current element which may be equipped with any time limit desired, and a selective watt element which is sensitive enough to indicate accurately which direction the power is flowing in the circuit, even at the lowest possible value of voltage. The co-operation of both elements is necessary in order to trip the circuit breaker. The statement has frequently been made that a reverse-power relay cannot operate when there is no voltage, but neither can there be a flow of current unless there is a difference of potential. The problem is therefore nothing more than a question of securing a contact-making wattmeter which is sensitive enough to operate on the small potential which is always present when a short-circuit occurs. The potential drop across the arc at the point of short-circuit, although small, is in itself sufficient to operate relays of the type shown in Figs. 1 and 2. Numerous tests have been made which show that when a cable breaks down, the arc through the insulating space between conductors will maintain a voltage of between one and two percent, and it has been found that a higher voltage is maintained when the current is small than when it is excessive, a fact which materially assists reverse-power relays. It should be pointed out that on large systems it is practically impossible to obtain a metallic short-circuit because any small object which could be brought into contact with the bus-bars would be immediately destroyed. The only possibility for obtaining a short-circuit which will lower the voltage to a point where reverse-power relays cannot operate is the case of an extra high-voltage system where the short-circuit current is so small that it cannot burn off a metallic connection. For instance, on a 150 000 volt system of some magnitude, the current at short-circuit may not exceed 500 amperes, which could be carried for some seconds by a telephone wire dropped across a transmission line. The possibility of interruption from this cause is remote, because a short-circuit across three wires will not often occur, and when only two wires are involved the low-voltage condition does not exist except on one phase.

EFFECT OF UNBALANCED SHORT-CIRCUITS

In the past the operation of reverse-power relays has been somewhat unsatisfactory, because means were not taken to insure correct operation at times when the power-factor of the system was bad, due to unbalanced short-circuits. As a result of several years' investigation, it has been found that the method of connecting reverse-power relays with their potential coils in star, as has been the usual custom, is theoretically incorrect, and the relays will fail to operate upon the occurrence of the most common form of short-circuit. When unbalanced short-circuits occur, a large number of combinations of

circumstances are possible, but it has been found that the most severe condition is when only two conductors of a three-phase line are short-circuited, and if relays will operate properly under this condition they will satisfy practically all the others.

In Figs. 15 and 16 are shown in a rather incomplete way the vector relations on a simple electric circuit when a short-circuit occurs between the wires B and C. Fig.

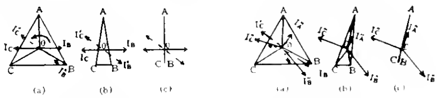

FIG. 15 FIG. 16

Fig. 15—Short-circuit on an unloaded circuit.
Fig. 16—Short-circuit on a loaded circuit.

15 shows at a the voltage triangle at the generating station and at b the voltage triangle some distance from the generating station. At c is represented the conditions at the short-circuit, and it will be seen that the long sides of the voltage triangle have closed in together. It will also be observed that the two star voltages, OB and OC, are in phase. Referring again to a, if the circuit has no inductance, the current which flows into the short-circuit will be in phase with the voltage BC, as is shown by the vectors I_B and I_C. If such a condition were possible, none of the relays at the short circuit could operate, because the power factor is zero. Since, however, there is always inductance in the circuit, the current will lag somewhat, as shown by the vectors I'_B and I'_C. The result of this is to cause one of the relays at the short-circuit to operate forwards and the other one to operate backwards. Fig. 16 shows the effect of an inductive load on the system. The short-circuit currents are represented by dash vectors, and the resultant of the short-circuit currents and load currents by heavy vectors. The general result of the load current on the system is to make less pronounced the effect due to the short-circuit, as will be observed upon comparing b in Figs. 15 and 16. In the former case one of the relays operates backwards, but in the latter case both of them read properly.

In the above explanation, the condition in only one line has been shown, and the question might immediately arise as to what difference it makes whether or not one relay operates backwards, so long as one of them operates to trip the circuit breaker. The answer is that the same condition exists in all the good sections of line adjacent to the trouble, with the result that their circuit breakers will also be opened.

One method of curing this trouble is very simple. Since the distorted condition is due to a single-phase being short-circuited, the relays should be connected with the potential coils across the same conductors which are causing the short-circuit. In other words, the potential coils should be connected in delta in accordance with Fig. 17. Because the current will lag behind the voltage when a short-circuit occurs, the connection should be so made that at unity power-factor the current in the current coils of the relays will lead the potential by 30 degrees. This connection not only overcomes the trouble from distortion, but it allows the relays at all times to operate under a higher power-factor. In order to make this connection satisfactory it is necessary to take into account the direction of the rotation of phases.

The above discussion is not based solely upon the mathematical study of the problem, but is the results of actual tests made on a number of transmission lines where the reverse-energy relays connected according to the old method have not given satisfactory service. Experiments have shown that this method of connection should also be used on systems having a grounded neutral. This connection (with the current 30 degrees ahead of the voltage) must be used with care on an ungrounded neutral system having a heavy charging current to ground. Difficulty may also be encountered on some systems where the load current is leading. But in both these cases the short-circuit currents will be much greater than any possible leading current and no difficulty due to incorrect operation of the reverse-power relays will be experienced if the excess-current elements are adjusted to operate only on short-circuits.

Overload and Reverse-Current Relays—Various manufacturers have in the past made a type of relay which would operate on a heavy overload in either direction and would also operate on a small overload in reverse direction. Such a relay is occasionally desired for the purpose of limiting the amount of power which can flow into a piece of apparatus, but it is not satisfactory for line sectionalizing and its manufacture has been almost abandoned. The principal objection to it is that its operation cannot be foretold when unbalanced short-circuits occur.

Current Transformers Required—To insure satisfactory protection on a grounded neutral system, current transformers should be placed in each wire, and it is advisable to do the same on an ungrounded neutral sys-

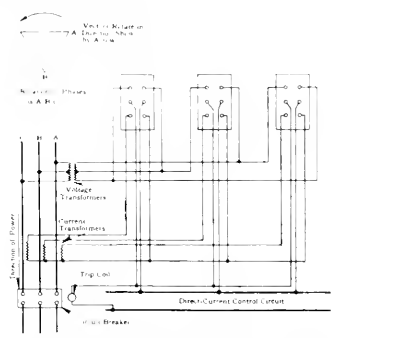

FIG. 17—CONNECTION OF RELAYS TO CAUSE THE CURRENT TO LEAD THE VOLTAGE ON NON-INDUCTIVE LOADS

tem. This is because two conductors in different phases of different sections of line are likely to be grounded simultaneously, thus resulting in a short-circuit which involves two line sections. For instance, suppose that phase A in one section of line becomes grounded and the resulting surge in voltage causes a breakdown in

another section of line in phase *B*. If both of these wires should happen to be without current transformers, the short-circuit could not be cleared. This is not a fanciful example, but is one which occurs quite frequently on overhead lines, due to the simultaneous flashover of two or more insulators. Even if no such trouble is feared, there is an advantage in using three current transformers and three relays at every switching point, because by such means additional insurance is provided against the failure of any one relay to operate. This applies particularly to reverse-power relays under conditions where only two wires are short-circuited, because then one of the relays is operated under very low voltage.

Potential Transformers Required—Two potential transformers connected in *V* are sufficient to operate three reverse-power relays. On high-voltage systems it is sometimes inconvenient to connect potential transformers on the line side of the power transformers, in which case they may be connected to the low-voltage bus-bars. If the power transformers are connected star-delta, the potential transformers should be connected the same way in order to bring the phases into the proper relation.

THE PROTECTION OF APPARATUS

It is not our intention to cover the protection of apparatus under all possible conditions, but only to mention those which are more intimately connected with the question of continuous service, and such cases as are particularly affected by disturbances on the distribution lines.

Transformers—In general, the current which can flow through rotating apparatus is limited to a reasonable value, and quick action in disconnecting such apparatus from the system is not essential. Transformers having low internal reactance are quite likely to be damaged in a few seconds if they are short-circuited, and a means of protecting them against internal short-circuits is shown in Fig. 18. The current transformers in the corresponding primary and secondary leads have their ratios so chosen that the current is equal through both secondaries. The normal current, therefore, circulates through the two transformers and does not pass through the relay because of its impedance. If a short-circuit occurs in the power transformer, the current through the current transformers will be reversed in direction so that it cannot circulate through them, but will flow through the relay and cause it to operate. It is possible that the ratio of the power transformer may be such that standard current transformers placed in its primary and secondary will not have equal secondary currents, in which case the difference between the two currents will flow through the relay. There is no particular disadvantage in this if the relay is given a sufficiently high current setting.

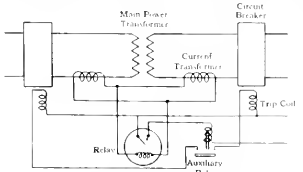

FIG. 18—PROTECTION OF A TRANSFORMER

Generators—It has been considered bad practice to place automatic devices in alternator circuits, because overload relays could not be set accurately enough and reverse-power relays were unreliable. However, some engineers insist upon generator protection because of the extensive damage which will occur before a short-circuited generator can be disconnected by the operator. Fig. 19 shows a scheme for connecting balanced current-transformers similar to that shown in Fig. 18. It will protect against occurrence of short-circuits in the generator windings or in the leads, and it will not introduce any risks of disconnecting the generator upon the occurrence of an overload; but it has the objection of requiring the opening of the generator winding at the neutral point, which is often difficult, and it cannot well be applied to delta-connected machines. It is believed that satisfactory protection can be obtained against generator failures by installing reverse-power relays to operate on a current slightly less than the sustained short-circuit value of the generator and with a definite time-limit of say one-half second. This will not disconnect the generator upon loss of field if it is carrying load, although it might disconnect it if it is unloaded.

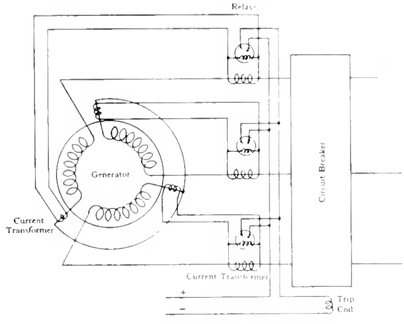

FIG. 19—PROTECTION OF A GENERATOR

Motors—The protection of motors has been thoroughly standardized, the only doubtful feature of existing practice being the often unnecessary use of the low-voltage release; a short-circuit on a distribution system frequently lowers the voltage at a sub-station to such a value as to have the same effect as an interruption. If the system is properly sectionalized a short-circuit should be cleared within three seconds, and practically any motor load will withstand such a disturbance without inconvenience. It is therefore obvious that the use of a device which will instantly disconnect a motor when the voltage falls to a low value does not assist in maintaining continuous service. It is better practice to equip the low-voltage release with a short time-limit, or to omit it entirely and depend upon an overload device for protection.

The effect of a short-circuit on a distribution system should also be considered when adjusting the overload device on a motor. When an unbalanced short-circuit,

such as has been previously described, occurs on a system, all motors, both synchronous and induction, attempt to maintain a balanced voltage on all three phases. A motor under such conditions will receive power from the good phases and send it back into the line over the bad phase, with the result that the current in all three wires is excessive. Overload protective devices on motors should therefore have sufficient time limit to allow the sectionalizing circuit breakers on the distribution system to clear the trouble before the motors will be disconnected.

Protecting Three-Phase, Star-Delta Transformers—A three-phase bank of star-delta transformers, having a grounded neutral, acts in a manner similar to an induction motor in that it attempts to maintain the voltage equal on all three phases. As a result, if a ground occurs on the distribution system, the star-delta transformers will supply current to the grounded wire, irrespective of whether these transformers are at substations or generating stations. In other words, if a small bank of transformers is connected to a large system, and has its neutral grounded, it will be subject to short-circuit conditions every time there is a ground on the distribution system. For this reason banks of small transformers should have their neutrals isolated, not only because of the strain which frequent short-circuits throw on them, but also because of the frequent interruptions caused to the customer.

The above argument applies principally to high-voltage systems, but it is necessary to consider the same conditions on a low-voltage four-wire system. Four-wire systems are usually used when a large amount of single-phase load is to be distributed, and as a result the voltage on the three phases is liable to be unbalanced. When a bank of delta-star transformers is connected on to such a system, the question of grounding the neutral must be carefully considered. As a rule, it is dangerous to make such a connection if the transformers are small, but if they are large it may be advisable to utilize them to assist in maintaining balanced voltage. The balancing is effected by drawing current from the high-voltage phases and supplying it to the low-voltage phase, with the result that there is a flow of current through the neutral connection. The possibility of burning out the transformers can be prevented by installing an overload relay in the neutral connection and connecting it so it will sound an alarm or automatically open the neutral.

It frequently happens that star-delta transformers are connected to the main circuit through fuses, and trouble is encountered when a single fuse is opened. If the transformer neutral is ungrounded, the load will operate single-phase, with the possibility of injuring the motors. On the other hand, if the neutral is grounded, two of the transformers will carry all the load at a much lower power-factor than normal. Usually there is no way of knowing that the fuse is blown, with the result that the transformers will continue to carry the overload until they are destroyed. A relay installed in the neutral and arranged to give an alarm seems to be the best means of preventing the transformers from being damaged.

Protecting Small Substations—It sometimes happens that a substation is supplied by duplicate feeders which are equipped with reverse-power relays to operate in case of line trouble, and it is desired to install overload relays which will open both circuit breakers in case of trouble on the substation bus-bars. This can be done by installing overload relays in series with the reverse-power relay, but the time setting must be sufficiently high so that the operation of the reverse-power relays will not be interfered with. A further disadvantage is that the setting of the overload relays must be changed whenever one of the lines is disconnected if it is desirable to maintain the same degree of protection. Both these objections can be overcome by installing an overload relay in such a way that it is operated by the total current flowing into the substation in the manner shown in Fig. 20.

DETAILS OF RELAY CONSTRUCTION

The Plunger Type of overload relay, although widely used for simple applications, such as the protection of motors, is not adapted to the accurate work required in

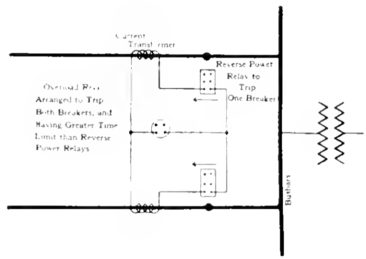

FIG. 20 PROTECTION OF A SUBSTATION SUPPLIED BY DUPLICATE LINES

automatically sectionalizing distribution networks. Some of these relays now on the market have received a bad reputation because of their poor workmanship and design. One difficulty is that the continuous vibration to which they are subjected gradually loosens the set screws and other parts, with the result that they fail to operate at a critical time . It must be remembered that the force on the plunger increases as the square of the increase in current, with the result that the forces reach enormous values when heavy short-circuits occur. It is, therefore, no uncommon thing for relays of this type to be so seriously damaged by a heavy short-circuit that they will not operate when another, milder, short-circuit occurs.

Bellows Type—The plunger type relays which depend upon a bellows for their time limit are unsatisfactory, because an extreme short-circuit compresses the air in the bellows until contact is made, and then at the zero point in the current wave, when the force on the plunger is released, the air in the bellows expands and opens the contact. This "chattering" not only causes the contacts to be badly damaged by the arcing, but delays the opening of the circuit breaker. The definite-time

relay is usually so designed that, when the core is lifted, it compresses a spring which, in turn, acts upon the bellows. After the core has been lifted, the current required to hold it in the raised position is much less than that required to lift it, with the result that the relay will not reset until the overload has decreased to a current much smaller than the tripping value.

Oil Dash Pot—The plunger-type relay, having an oil-filled dash pot as its time-limit device, cannot be used for automatic sectionalizing because of the great change in the viscosity due to changes in temperature .

Expense of Adjustment—An objection to the use of all such relays is that the expense of adjusting them for accurate work is oftentimes greater than the cost of the relays themselves. It is possible that an automatic sectionalizing scheme could be so laid out that time limits varying by steps of one to two seconds could be used, in which case the bellows type of relay might be sufficiently accurate, but such accuracy could not be obtained except at considerable expense. In order to adjust relays of this type it is necessary to disconnect them from the circuit and connect them to a test circuit which, in many cases, is not easy to obtain. In addition, a chronograph, ammeter and control device are necessary. Needless to say, such a calibration must be made by a skilled tester. If a change in the time limit is later required it is necessary to repeat the entire process.

Induction Type—The best feature of the induction type of overload relay is its remarkable accuracy and permanence of calibration. The use of permanent magnets as a time-limit device prevents over-swinging and chattering of the contacts, and the construction is such that the relay will instantly cease its movement when the overload disappears. There is no possibility of mechanical injury due to excessive currents when the torque compensator is used, because the saturation of the iron prevents the mechanical forces from increasing beyond a certain amount.

Ease of Adjustment—The current and time adjustment of the induction relays shown in Figs. 1 and 2 are plainly and accurately marked and any desired change can be made at a moment's notice. This is a feature much appreciated by the operating man who is responsible for the successful operation of the automatic sectionalizing devices on his system. He can personally check the setting of every relay and thus be sure that no incorrect operation will result due to the carelessness or incompetence of an assistant.

Relay Contacts—One difficulty in relay operation which requires consideration is that which occurs due to the burning of the contacts when heavy tripping currents are handled. The tripping circuits are, as a rule, highly inductive, and an arc which would be formed due to opening such a circuit will persist for a considerable length of time, and thus cause an unnecessary amount of burning on the relay contacts. For this reason it is necessary that the tripping circuit be opened by an auxiliary switch fastened to the circuit breaker in such a way that the opening of the circuit breaker automatically opens the tripping circuit. It sometimes happens that large circuit breakers require a much heavier current to trip them than can safely be carried by the relays. This difficulty is overcome by the use of an auxiliary relay switch which is operated by the protective relay and which closes the tripping circuit of the main circuit breaker. A relay switch is also used when it is desired to trip several circuit breakers from one relay.

Series Tripping—The usual method of tripping circuit breakers is by means of a trip coil operated by direct current, and for this purpose relays known as "circuit-closing" relays are used. Where a source of direct-current power is not available it has been customary to use "circuit-opening" relays which normally short-circuit the trip coil of the circuit breaker—when the relay operates; it opens this short-circuit and allows current from the current transformer to energize the trip coil. In theory this scheme operates very nicely, but in practice it has been found that the short-circuiting device is quite likely to develop a high resistance in its contacts, which will cause the trip coil to operate when there is no occasion for it to do so. Up to the present time no satisfactory circuit-opening protective relay has been placed on the market, a statement which can easily be proved by referring to the changes which manufacturers are continually making in the design of this type of relay. All the difficulties which occurred with the circuit-opening relay have been overcome by the development of the "direct-trip attachment," which utilizes current from the current transformer to trip the circuit breaker, but which operates with a circuit-closing relay.

Load on Instrument Transformer—When selecting a relay for use on current transformers which also operate instruments, it is important to consider the load which the relay places on the transformer. The induction type of relay requires a smaller amount of energy than does any other type, a feature to be appreciated when bushing-type current transformers are used. When transformers of this type are heavily loaded their ratio is not constant and there is also a noticeable difference in phase between the primary and secondary current. The reverse-power relays shown in Fig. 2 require such a small amount of energy that the phase angle error will not be great enough to affect their operation even if they are used on bushing-type current transformers having a small ratio of transformation.

Convenience in Testing—In selecting a reverse-power relay it is not only important to obtain one having satisfactory operating characteristics, but the question of convenience in checking its connections must be considered. If the relay is a sensitive one, it can be tested by feeding a small amount of power through it in the reverse direction. On some systems the power loss in a bank of transformers located on the line side of the relays may be sufficient to cause their selective elements to operate backwards and thus test their reliability. On the other hand, a relay which required five or ten per cent reversal of power in order to operate it cannot be tested except at great expense, and it is usually necessary to determine by more or less costly experience whether or not the relays are connected backwards.

Polarity of Transformers

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THE term "polarity" has become recognized as defining the direction of flow of current at the terminals of electrical apparatus. In connection with transformers it indicates the relative directions of the currents in the primary and secondary leads at any given instant. In analyzing the polarity of a transformer, a primary line lead and a secondary line lead, brought out of the case on the same side of the transformer, as leads *X* and *A*, Fig. 1, are used for reference.

DIRECTION OF INSTANTANEOUS VOLTAGES AND CURRENTS

An arrangement of coils, which is typical of the shell-type transformer, is shown in Fig. 1, and illustrates the polarity which is standard for Westinghouse power transformers. For simplicity, only two primary and two secondary coils, grouped in a *L-H-H-L* arrangement, are shown, although in actual practice more coils are used. Small transformers use this grouping (called *2 HL* from the number of groups of opposed high-voltage and low-voltage coils), while in larger transformers the coils are split up into a greater number of similar groupings (*4 HL, 6 HL, 8 HL*, etc.).

The terminals of a generator are assumed to be connected to the low-voltage coils, Fig. 1, and the impressed voltage at a given instant is assumed to be in the direction from *X* to *Y*. The flux caused by this impressed voltage induces voltages in both primary and secondary coils which are in the same direction; i. e., from *Y* to *X* in the primary coils and from *B* to *A* in the secondary coils. In the primary coils this induced voltage is a counter e.m.f. which directly opposes the impressed voltage. This counter e.m.f. is enough less than the impressed voltage to allow the load current to flow.

The potential above ground of a winding whose voltage is impressed from an outside source falls progressively from the high potential, or positive end of the winding, to the low potential, or negative end, and the direction of the flow of current is from the positive end to the negative end. On the other hand, in a winding within which voltage is induced, the potential above ground rises progressively from the low potential end of the winding to the high potential end, and the current is pumped up, as it were, from the low potential or negative end to the high potential or positive end. The arrows used in the figures indicate instantaneous directions of voltages and currents, and the high potential and low potential points of the windings are marked + and —, respectively. Half a cycle later all arrows will be reversed, but the relative directions will be unchanged.

The same conditions as regards relative directions of voltages and currents are present in a core-type transformer as in a shell-type transformer, and the general discussion throughout applies equally well to both types.

KINDS OF POLARITY

In making up the assembly of the primary and secondary coils and their connections either one of two polarities, called "subtractive" or "additive," may be produced. The relative directions of the currents in the external primary and secondary leads depend upon whether the coils are assembled, as shown in Fig.

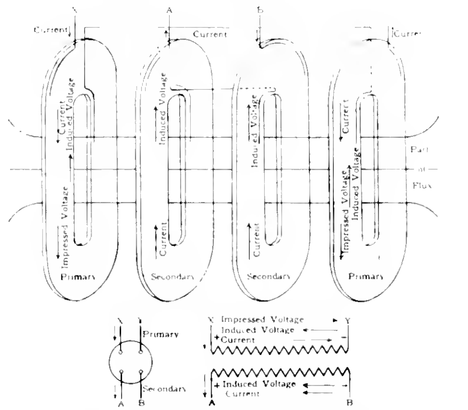


FIG. 1—DIRECTIONS OF INSTANTANEOUS VOLTAGES AND CURRENTS WITH A SUBTRACTIVE WINDING POLARITY

1, or whether the coils of either one of the windings are reversed. This assembly of the coils, therefore, fixes the winding polarity. If the leads coming from either the primary or the secondary coils are crossed before they are brought through the case, the relative directions of the currents in the external leads are changed and the external polarity of the transformer is changed. The external polarity, therefore, depends not only upon the winding polarity, but also upon the connections of the coils and external leads. It is generally undesirable to cross the leads inside the case on account of the difficulty in getting sufficient clearance between them for mechanical and electrical reasons, and throughout this discussion the leads are assumed to be brought out straight from the coils through the case, which is the natural and logical arrangement.

As far as the delivery of power by the secondary winding is concerned, it makes no difference which way the coils are assembled and the connections are made.

From the standpoint of voltage stresses between coils, however, the choice of winding polarity in many cases has a great deal to do with the cost and reliability of the transformer.

SUBTRACTIVE POLARITY

With the coils assembled and connected as in Fig. 1, the directions of the currents in the leads at a given

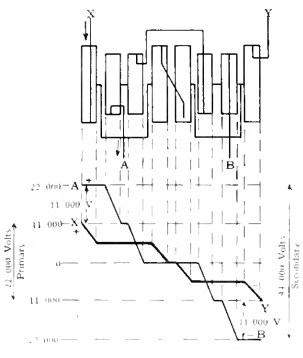


FIG. 2—SUBTRACTIVE POLARITY

Showing voltage stresses between leads and coils of a 44 000 to 22 000 volt transformer under normal conditions when the middle points of the windings are neutral points at zero or ground potential. The vertical distances represent induced voltages. The sloping line under each coil represents the voltage induced in that coil. Light lines represent the potentials of the high-voltage coils, and the heavy lines the potential of the low-voltage coils. The vertical distance between the light and heavy lines represents difference of potential or voltage stresses.

instant are as shown by the arrows. At any instant the voltage stresses between points in the coils are proportional to the difference of potential between such points. It will be seen that the ends of the windings connected to *A* and *X* are positive and have a potential *above* ground at the instant when the currents and voltages are as shown, and at the same instant the ends of the windings connected to *B* and *Y* are negative and have a potential *lower* than ground potential. The potentials of adjacent points in the windings are obviously more nearly equal when they are of the same sign

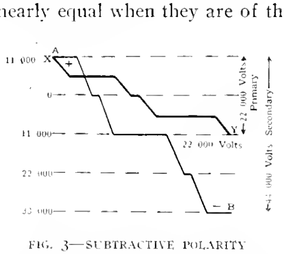


FIG. 3—SUBTRACTIVE POLARITY

Representing accidental contact between leads *A* and *X* on the same side of the transformer. The voltage between leads *B* and *Y* is the difference between the voltages of the high and low-potential windings.

and the voltage stresses between such points are a minimum.

If the adjacent ends of the windings, such as *A* and *X* in Fig. 1, are connected together, the voltage stress between the free ends of the windings, *B* and *Y*, will be the *difference* between the voltages of the windings, hence the term subtractive polarity. In the A.I.E.E. Standardization Rules this polarity is referred to under "Transformer Connections" as that having "high and low-voltage windings in phase." It is sometimes called negative polarity.

To see the practical effects of subtractive polarity, assume that the transformer is one having a 4 H-L grouping of coils and a ratio of 44 000 to 22 000 volts. The voltages induced in the windings and the insulation stresses between coils and leads under normal conditions are as shown in Fig. 2. The difference of potential between leads *A* and *X* and between leads *B* and *Y* is only 11 000 volts, and the insulation stresses throughout the entire group of coils are low.

If leads *A* and *X* on the same side of the transformer, or the conductors connected to them, should accidentally come into contact, the potential of lead *A* would be the same as *X* and the successive potentials throughout the high-voltage winding would be as shown by the light line in Fig. 3. Under this abnormal condition the difference of potential between leads *B* and *Y*

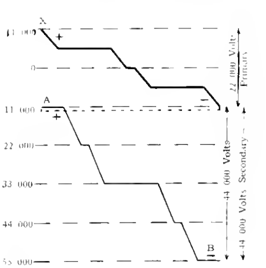


FIG. 4—SUBTRACTIVE POLARITY

Represents accidental contact between leads *A* and *Y* on opposite sides of the transformer.

would be 22 000 volts, which is the *difference* between the voltages of the two windings. If leads *B* and *Y* should come into contact this potential difference of 22 000 volts would appear between leads *A* and *X*.

If lead A on one side of the transformer should accidentally come into contact with lead *Y* on the other side of the transformer, the potential conditions throughout the windings would become as shown in Fig. 4. The difference of potential between leads *B* and *Y* becomes 44 000 volts. If, however, leads *B* and *X* should come into contact this 44 000 volt stress would appear between leads *A* and *X*.

The distinctive features of subtractive polarity may be summarized as follows:—

1—When the instantaneous flow of current is toward the transformer in the high-voltage lead, it is away from the transformer in the low-voltage lead on the same side of the transformer. The effect, as far as direction of current is concerned, is the same as if the circuit were continuous without the transformer connected in it.

2—If the adjacent ends of the high-voltage and low-voltage windings are connected together, the voltage existing between the free ends of the windings will be the difference between the voltages of the high-voltage and low-voltage windings.

ADDITIVE POLARITY

If the primary coils of Fig. 1 are reversed in position with respect to the other coils in such a way that the direction of the windings will be reversed, but the connections between the coils left unchanged, as

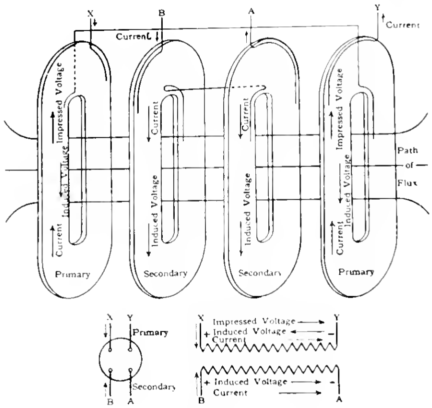


FIG. 5—DIRECTIONS OF INSTANTANEOUS VOLTAGES AND CURRENTS WITH ADDITIVE WINDING POLARITY

Standard for distributing transformers.

shown in Fig. 5, the relative directions of the voltages and of the currents in the external leads will be reversed. The polarity will be changed and the directions of the currents at a given instant will be as shown by the arrows. The same change of polarity would result if the secondary coils had been reversed in position with respect to the primary coils.

The induced voltages in Fig. 5 are such that adjacent ends of the windings have potentials of opposite sign at any instant. Obviously, then, the voltage stress between

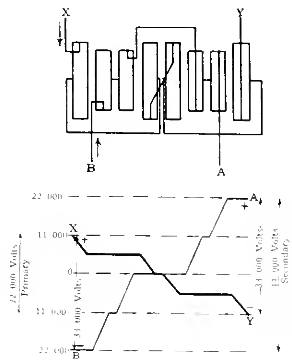


FIG. 6—ADDITIVE POLARITY

Voltage stresses under normal conditions.

any two adjacent points will be greater than if these points had potentials of the same sign. If the adjacent ends of the windings, such as B and X, are connected together, it will be found that the voltage stress between the free ends of the windings, A and Y, will be the *sum* of the voltages of the windings. This is the significance of the term additive polarity. The American Institute Standardization Rules, under "Transformer Connections," refer to this polarity as that having "high and low-voltage windings 180 degrees apart in phase." It is sometimes called positive polarity and, as it is the standard polarity for distributing transformers with all manufacturers, it is spoken of as "distributing polarity."

If the transformer, Fig. 5, is assumed to have a 4 H-L grouping of coils and a ratio of 44 000 to 22 000 volts as before, the potentials of the windings and the insulation stresses between coils and leads under normal conditions will be as shown in Fig. 6. The difference of potential between leads B and X and between leads A and Y is 33 000 volts, which is higher than with the subtractive polarity. The insulation stresses throughout the entire group of coils are similarly higher than with the subtractive polarity.

If leads B and X on the same side of the transformer should accidentally come into contact, the potential of lead B would become the same as lead X and the potentials throughout the high-voltage winding would be as shown by the light line in Fig. 7. Under this abnor-

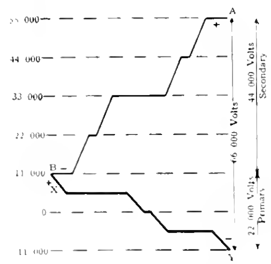


FIG. 7—ADDITIVE POLARITY

Represents accidental contact between leads B and X on the same side of the transformer. The voltage between leads A and Y is the sum of the voltages on the high and low-potential windings.

mal condition the difference of potential between leads A and Y would become 66 000 volts, which is the sum of the voltages induced in the two windings. If, on the other hand, leads A and Y should come into contact, this potential difference of 66 000 volts would appear between leads B and X.

If lead B on one side of the transformer should accidentally come into contact with lead Y on the other side of the transformer, the potential conditions would become as shown in Fig. 8. The difference of potential between leads A and Y becomes 44 000 volts. If leads A and X should come into contact this stress of 44 000 volts would appear between leads B and X.

The distinctive features of the additive polarity may be summarized as follows:—

1—When the instantaneous flow of current is toward the transformer in a high-voltage lead, it is also toward the transformer in the adjacent low-voltage lead on the same side of the transformer. The effect of placing the transformer in the circuit, as far as direction of current is concerned, is to reverse the flow of current in the system.

2—If the adjacent ends of the high-voltage and low-voltage windings be connected together, the voltage developed between the free ends of the windings will be the sum of the voltages of the high and low-voltage windings.

SUBTRACTIVE VERSUS ADDITIVE POLARITY

A direct comparison of the voltage stresses obtained under different conditions with the transformers used in the preceding examples reveals conditions favorable to subtractive polarity, as shown in Table I. The ratio of test voltage to maximum voltage stress in Table I shows that the insulation stresses with subtractive polarity are such that under worst conditions the standard insulation tests represent a ratio of two, and under normal conditions the factor of safety is very much increased. With the additive polarity the standard insulation test fails to provide a ratio of two under one condition, and under normal conditions the factor of safety is much less than with the subtractive polarity. To provide a ratio of two between the test voltage and the maximum voltage stress under abnormal conditions, with the additional 1000 volts prescribed by the A.I.E.E. rules, would require a test of 133 000 volts instead of 89 000 volts. This would require additional insulation to make the transformer safe and would involve the hazard of operating with needlessly high-voltage stresses.

TABLE I—COMPARISON OF POLARITIES

Conditions of Operation	Subtractive Polarity: Maximum Voltage Stress between Coils	Subtractive Polarity: Ratio of Test Voltage to Maximum Stress*	Additive Polarity: Maximum Voltage Stress between Coils	Additive Polarity: Ratio of Test Voltage to Maximum Stress*
Normal......	11000	8.09	33000	2.70
Leads on same side of transformer in contact.........	22000	4.04	66000	1.35
Leads on opposite sides of transformer in contact...	44000	2.02	44000	2.02

*Based on the standard test between windings of twice the normal voltage plus 1000, or 89 000 volts.

The conditions of insulation stress between coils in each phase of a three-phase transformer are exactly the same as in the case of a single-phase transformer. In connecting these phases together, however, there are a number of combinations possible in forming the star and delta connections. This makes possible a large number of different polarity combinations at the leads.

The choice of polarity is relatively unimportant, from an insulation point of view, when the voltage of one winding is a small percentage of the voltage of the other winding. With a ratio of 2200 to 220 volts, for instance, it matters little as far as insulation stresses are concerned whether the low voltage is added to, or subtracted from, the high voltage. This is the condition for the ordinary distributing transformer with a ratio of 2200 to 220 or 110 volts. Additive polarity was used in the early days of building transformers. It was continued until its use is now general for distributing transformers. The ratios and voltages usually involved in such transformers make the matter of polarity of less importance than a standard practice, and market conditions now require the additive polarity. In all cases,

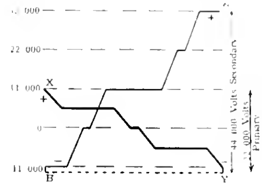


FIG. 8—ADDITIVE POLARITY
Represents accidental contact between leads B and Y on opposite sides of the transformer.

however, a safer and more reliable transformer results when the subtractive polarity is used, the degree of improvement depending upon the ratio of voltages.

STANDARDIZATION OF POLARITY MARKINGS

The latest rules of the A.I.E.E. provide for marking the high-voltage leads of single-phase transformers with the letters A and B and the low-voltage leads with the letters X and Y. These markings are to be applied so that the potential difference from A towards B will have the same sign at any instant as the potential difference from X towards Y. The markings used in the illustrations of this article agree with this convention.

The high-voltage leads of a three-phase transformer are to be marked A, B and C and the low-voltage leads X, Y and Z, or in the case of a six-phase, low-voltage winding the leads are to be marked U, V, W, X, Y and Z. These letters are applied so that if the phase sequence of voltage on the high-voltage side is in the order A to B to C, it will be in the order of X to Y to Z, or U to V to W, etc., on the low-voltage side. The phase combinations which are generally used are classified into groups in the A.I.E.E. Rules, as shown in Fig. 9.

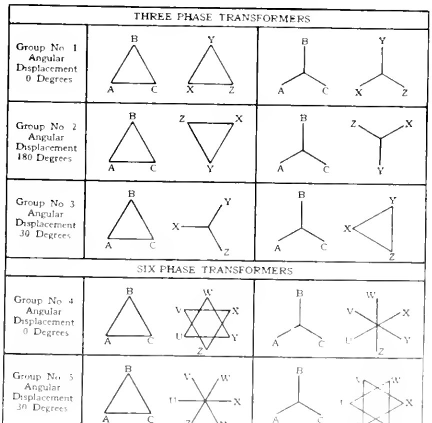
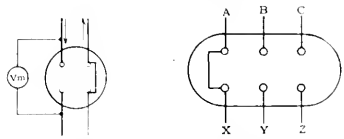


FIG. 9—A.I.E.E. CLASSIFICATION OF POLARITIES

PARALLEL OPERATION

Obviously, one of the requirements for operating transformers in parallel is that their polarities be the same, or that equivalent polarities be obtained by crossing their leads. With the markings prescribed by the Institute Rules it is necessary simply to connect together leads which are similarly marked, assuming that their voltages, ratios, resistances and reactances are such as to permit parallel operation. The crossing of their leads, which becomes necessary if the transformers are of different polarity, is generally practicable with single-phase transformers if it is done on the outside of the case, where there is usually plenty of room and where the wiring is easily accessible.

A great many of the combinations of interphase connections in the case of three-phase transformers produce angular displacements between the high-voltage and low-voltage circuits. For this reason it becomes necessary, before connecting three-phase transformers in parallel, not only to know that the voltages, ratios and impedances will permit parallel operation, but also to have determined that the angular displacements are the same. Transformers having connections as shown in any one group of Fig. 9 can be operated in parallel by connecting similarly marked leads together, if their other characteristics will permit. Transformers of one group, however, cannot be operated in parallel with transformers of any other group.



FIGS. 10 and 11—CONNECTIONS FOR TESTING POLARITY OF A SINGLE-PHASE AND THREE-PHASE TRANSFORMER

It is rarely possible to connect in parallel three-phase transformers having different polarities by crossing the leads on the outside of the case. The combinations of connections between phases which are possible often require that troublesome internal changes be made as well.

TESTING FOR POLARITY

Polarity of a single-phase transformer may easily be determined by exciting one winding and after connecting together the adjacent high-voltage and low-voltage leads on one side of the transformer, as shown in Fig. 10, connecting a voltmeter across the other two ends of the windings. If the voltmeter reads higher than the impressed voltage, the polarity is additive, and the leads which are tied together are the *A* and *Y* leads (or *B* and *X*). If the voltmeter reads lower than the impressed voltage, the polarity is subtractive and the leads tied together are the *A* and *X* leads (or *B* and *Y*).

Several different voltmeter readings are necessary to determine the polarity of a three-phase transformer definitely. A high-voltage and a low-voltage lead should be connected together as shown in Fig. 11. The transformer should then be excited by connecting either the high-voltage or low-voltage winding to a steady balanced three-phase source, and single-phase voltmeter readings should be taken successively across *A* and *B*, *B* and *Y*, *B* and *Z*, and *C* and *Z*. Three-phase transformers which are intended to operate in parallel should show identical voltage measurements across these various points when excited in the same way. With large ratios of transformation the differences between measurements made in checking the polarity will be small, and it is well to make a careful re-check by connecting a different pair of high and low-voltage leads together.*

The diagram in Fig. 12 shows the voltage relations of the delta-delta transformer of Group *1* in Fig. 9, when the *A* lead is connected to the *X* lead for testing the polarity. This diagram shows that the polarity of this group is subtractive. The voltage relations of the delta-delta transformer of Group *2* under test conditions are shown in Fig. 13. The polarity for this group is additive.

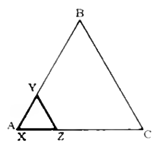


FIG. 12

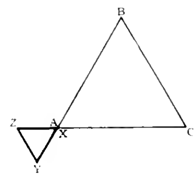


FIG. 13

Fig. 12—Diagram for checking polarity of delta-delta transformer in Group *1*, Fig. 9. Voltage measurement across *BY* equals that across *CZ*; voltage measurement across *BY* is less than that across *AB*; voltage measurement across *BY* is less than that across *BZ*.

Fig. 13—Diagram for checking polarity of delta-delta transformer in Group *2*, Fig. 9. Voltage measurement across *BY* is equal to that across *CZ*; voltage measurement across *BY* is greater than that across *AB*; voltage measurement across *BY* is greater than that across *BZ*.

In testing out the polarities of the other transformers in the groups of the Institute Rules it will be found that they are all subtractive except Group *2* and the double-delta transformers of Groups *4* and *5*. In the latter, the polarity of one delta is necessarily the reverse of the other to get the six-phase relations, so that one is additive and the other subtractive.

*See article on "Determination of Polarity of Transformers for Parallel Operation," by Mr. W. M. McConahey, in the JOURNAL for July, 1912, p. 613.

Recent Improvements in Radio Communication

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When radiotelegraphy was made practicable by Marconi, the new art appealed to popular imagination to an extent not reached by any other recent invention. Even today the wonder of "wireless" has not diminished greatly. The appeal to scientific investigators was as great as to popular fancy, and specialists in many branches of science were attracted to work on the problems presented. This has resulted in a very rapid development of the art, especially in the last two years, in which time radical improvements have been made. Furthermore, these improvements have been of such a nature as to open up new and fertile fields for experiment, so that still greater progress may be expected. Today the electrical engineer who has not come into close contact with radio problems knows little about them. This is not surprising, since radioengineering has been highly specialized, and the electrical engineer has felt little need for radio or other high-frequency applications. Now, due to certain developments in both the general electrical field and in the special radio branch, each is finding more use for the other.*

The fundamental requirement of a radio system is that in the radiating part, commonly formed by conductors suspended in the air and forming with the earth, or other conductors placed underneath, a radiative condenser, there must be generated a current whose frequency is high, since the energy radiated is a function of the frequency. Features of the generation and radiation of the currents place limitations upon the range of frequencies which can be used, which is at present from about twenty thousand to one or two million cycles a second. The different methods of generating this high-frequency current for the antenna distinguish the different systems of radio transmission.

The first method, the one used by Marconi in his first work, obtained the high-frequency current from the oscillatory discharge of condensers. He used the antenna not only to radiate, but as the condenser which should be charged and discharged. This method has been developed until today it is probably near the limit of its possibilities. This method is the one still in most common use, and bids fair to hold its own for some time to come, particularly in ship installations, because of its greater simplicity and ease of operation as contrasted with later systems.

The operation of the condenser discharge method, in improved form called impulse excitation, is as follows:—A source of high voltage is used to charge a condenser. This source is usually an alternating one, since that can be more easily obtained and controlled, although continuous voltage can be used, and is used in some stations. This condenser charges to a voltage sufficient to break down a spark gap which is part of a closed discharge circuit for the condenser. The condenser then discharges through this circuit with decaying oscillatory current at a frequency determined by the constants of the circuit. The remaining part of the discharge circuit is an inductance which forms the primary of an air-core transformer, whose secondary is in series with the antenna circuit. Each discharge of the condenser, then, induces a voltage in the antenna. If the antenna constants are arranged for resonance to the frequency of the condenser current, maximum current will be obtained. The arrangement of parts, as practiced in modern sets of this type, is shown in Fig. 1. The spark gap is the part of chief interest, as different designs of spark gaps give different characteristics of operation. The old spark gap consisted simply of two stationary electrodes. There are many objections to this simple arrangement.

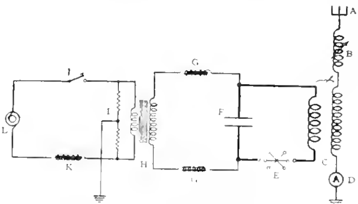

FIG. 1—SPARK TRANSMITTER

A—Antenna; *B*—Variable inductance for tuning antenna; *C*—Oscillation coupler; *D*—Radiation ammeter; *E*—Spark gap; *F*—Condenser; *G*—Choke coils to prevent high-frequency surges from appearing in the audio frequency circuits; *H*—Step-up transformer; *I*—Protective resistances, for same purpose as choke coils; *J*—Sending key; *K*—Variable reactance for controlling regulation of the transformer; *L*—Alternator

It is desirable that the gap open quickly after the condenser discharges, in order that its circuit shall be open and therefore not reacting with the antenna circuit coupled to it. If there is *continued reaction* between these circuits, the antenna current will be damped out more rapidly, and this is not desired. In the stationary gap, without air blasts or other quenching means, the arc holds on, permitting reaction. Incidentally, more power is consumed, which is dissipated in undesired heating and burning away of the electrodes, etc. This is the chief objection to the stationary gap, and an improved design must not permit this action. There are two improved designs of spark gaps which meet the requirement—the synchronous rotary gap and the quenched gap. One or the other of these types is always used in modern spark sets.

The synchronous gap has rotating electrodes so arranged as to be brought close to fixed electrodes at each maximum of the condenser voltage. The condenser then

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*See also article on "Present Practice in Radio-Telegraphy," by Mr S. M. Kintner, in the Journal for September, 1913, p. 817.

discharges at a regular rate, and gives trains of oscillations evenly spaced, which produces a musical note. The rotation of the electrodes cools the gap and aids in quenching the arc. This type of gap was invented by Prof. R. A. Fessenden and was an enormous improvement over the old stationary gap.

The quenched gap consists of several fixed plates at small separation, so enclosed that the sparking surfaces are air-tight. Due to the small separation, there is only a small voltage across each gap. If the inductive coupling between the discharge circuit and the antenna circuit be rather close, the antenna circuit will react upon the condenser discharge circuit and the resultant condenser gap current will have beats. At the first minimum of the voltage (or possibly the second or third) across the gap, the value of the voltage will be insufficient to sustain the arc and it will go out, leaving the condenser gap circuit open until the next discharge of the condenser. Meanwhile the antenna continues to dissipate the energy given to it by the impulse from the condenser, but its decaying current will be much less damped than if energy were being taken from it by a closed condenser circuit. This non-damping of the antenna current is the condition desired, for the reasons outlined later. Adjustments for best operation of this type of gap are rather critical, but, when properly made, the gap gives very satisfactory service. The quenched gap has a few better points than the synchronous gap and is usually preferred.

Improvements in gap design are still being made. A new type has been described recently* which gives true impulse excitation, that is, the condenser discharge is so rapidly quenched that it persists only one alternation. This is accomplished by making the ratio of capacity to inductance very large, giving large damping, and working the gap in hydrogen atmosphere. This single alternation gives up its energy to the antenna circuit closely coupled to it. That this is true impulse excitation is nicely shown by a feature of the operation which has considerable practical advantage, that the condenser circuit need not be tuned to resonance with the antenna. The antenna is excited by the impulse and then oscillates at its own natural frequency, whatever the natural frequency of the exciting circuit may be, since the exciting current lasts only one-half cycle anyway. The wave length can be changed, then, by simply changing the constants of the antenna only. If this type of gap proves reliable in operation, it should be an improvement over those now in use.

The supply frequency now used almost exclusively is five hundred cycles, since that frequency, to obtain given power outputs, requires smaller size condensers and lower voltages than do lower frequencies; gives a note more pleasing and one to which the ear is most sensitive, and one more easily read through atmospheric interference; gives a greater over-all efficiency than a lower frequency.

*Proceedings Institute of Radio Engineers, June, 1916.

The chief advantage of the spark method of generation is that it can be easily installed on ship or shore, is rugged and requires little expert attention when once adjusted. Its chief disadvantage is that its antenna current is damped, being a free oscillation, and therefore does not emit radiations of a single frequency, with consequent "less sharp" tuning at the receiving station. This type of generation gives what is usually called damped wave or grouped wave transmission. If, instead of these grouped waves, with a certain number of wave trains (condenser discharges) per second, we could have a continuous forced current, better tuning effects could be secured, as well as some other advantages mentioned later. This is accomplished by each of the three other methods of generation now possible, which give what is called sustained wave transmission, in distinction to the grouped wave transmission.

One of these methods is direct generation by a high-frequency alternator. To Prof. Fessenden is due the credit for the development of the first successful machine of this kind. Mr. Alexanderson has since perfected these alternators, and they can now be made for outputs of 100 kw or more. These machines are of the inductor type. Another type in successful operation in radio stations is the Goldschmidt alternator, which generates a fundamental voltage of two or three thousand cycles, a harmonic of which is magnified by suitable condensers and inductances. This can be carried through several steps in cascade (in separate machines or in the same armature) to the final frequency desired. The alternator can be put directly in the antenna or inductively coupled to it, as shown in Fig. 2. The alternator method of generation is not common today, since the machines are very expensive, require attention and do not permit easy change of wave length, that is, frequency of voltage generated. However, its development to practicability is an important step in the improvement of transmission, and its present usefulness is great for high-powered land stations, such as are used for transoceanic communication.

The next method is that of arc generation. This employs the Duddell arc principle, with special features of design which permit the withdrawal of large amounts of energy, and is known as the Poulsen arc. The arc is a most interesting device, and its development to a state where it is thoroughly reliable has been the most important recent advance in transmission, with the possible exception of the recent development of an entirely new method of generation. The importance of the arc development lies in the fact that, due to it, the use of sustained waves is rapidly extending, and the use of sustained waves means a distinct advance. The disadvantages of the arc are that it requires some attention, electrodes require replacement, etc., but these are more than offset by the advantages of lesser first cost, simple control and easy change of wave length. It is reported that this type of generation has been chosen by the United States Navy for the high-powered stations in the United States and foreign possessions.

In controlling the output of the continuous wave generators to send dots and dashes, the whole power of the generator does not need to be broken. One method, that used with arcs and sometimes with alternators, has the sending key so arranged that when depressed a certain value of inductance is in the antenna circuit, and when the key is open, a certain other value. Thus, the key might be arranged to short-circuit a portion of the

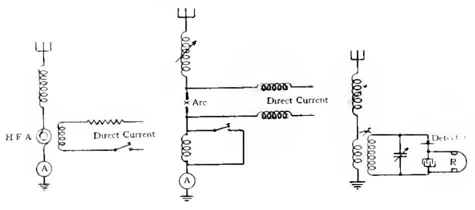

FIG. 2 FIG. 3 FIG. 4

Fig. 2—High-frequency alternator with field control for sending.
Fig. 3—Arc generator with detuning control for sending.
Fig. 4—Inductively coupled receiver.

antenna inductance. Then the station will emit two wave lengths, one when the key is down and another when the key is up. A receiving station can hear either of these waves to which it may tune, but only one will make intelligible code signals, and the receiving operator has no difficulty choosing the correct one. Another method, applicable to alternators, is to make and break the field circuit of the alternator by the key according to the signals desired. The time constant of the field circuit is made such, by the insertion of resistance, that full field current may be established and interrupted as quickly as is necessary.

The new method of high-frequency current generation is very promising, and is an unexpected development of a device which has been in use for a number of years, the audion. It was by means of this method that the recent long-distance radio-telephone transmission was accomplished. Details of this method have not been made public, and it can be described only superficially. First, however, it is best to consider the reception of radio signals, since a better understanding of the use of the audion for transmission will result from a clear conception of its action in receiving circuits. The most marked progress in the last year or two has been in reception, and in this field results have been truly startling.

Methods of reception in use for many years have made use of coupled resonant circuits, with a detector of some form in the secondary circuit, whose function was to rectify the alternating current due to the received signal, or otherwise permit the use of sensitive telephone receivers as an indicating device. One such circuit, more or less the standard one, is shown in Fig. 4. The detectors have been the common crystal rectifiers, Fessenden's electrolytic type, Marconi's magnetic type, Fleming's gas valve, and the DeForest audion. It is the modifications of the connections of the last named which have given enormous increase in receiving efficiency. The audion circuits as invented by Dr. DeForest, and as used for several years, are shown in Fig. 5. The audion is a glass bulb highly exhausted, with a tungsten incandescent filament, designed usually for four or six volts, and with two electrodes mounted near the filament in such a way that one, called the grid, a zigzag wire or perforated plate, is between the filament and the other electrode. The latter electrode is called the plate or wing, and is usually a small nickel plate.

Explanation of the audion action, according to the present theory, briefly, is this. The incandescent filament gives off negative ions which permit current between the wing and filament from the battery B through the telephone receiver R. Under steady conditions, with no incoming oscillation applied to the audion, the telephone current will be unvarying, consequently producing no sound in the telephone. When alternating current, due to the received signal, flows in the closed circuit L_2 C_2, the alternating voltage of the condenser C_2 is applied to the condenser C_3 and the grid-filament path of the audion in series. The filament being incandescent and the grid relatively cold, the two constitute a gas valve which permits flow of current in one direction only, namely, from the grid to the filament. When a current flows through condenser C_3 in one direction, a charge accumulates on it. In this case the charge is negative. This charge on C_3 raises the potential (negative) of the grid to which it is connected. It has been observed that a negative potential of the grid with respect to the filament decreases the wing current flow, and a positive potential increases it. Therefore, the negative charge on the grid caused by the signal decreases the wing filament current. This decreasal of the current through the telephone gives an audible sound in it—there being one vibration for each incoming train of oscillations, that is, for each spark of the sending station transmitter. The pitch of the signal heard at the receiving station, then, will be the same as that of the spark at the sending station. It should be noted that this rectifying action and decrease of wing current takes place for each cycle of the radio frequency applied to the grid, and that there will be, therefore, a radio frequency current in the wing-filament circuit (the device

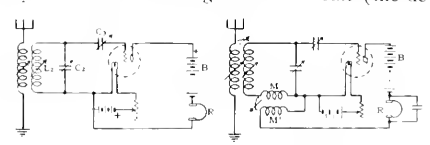

FIG. 5 FIG. 6

Fig. 5—Use of audion as a valve.
Fig. 6—Use of audion as an amplifier.

acting as a repeater) superimposed on the continuous current from the battery, when the constants of the circuit are right for the action. When telephone receivers are inserted, the current is smoothed out so that there will be one pulse of current, and one impulse to the telephone diaphragm, for each *train* of oscillations. In short, the audion is a "trigger" device, giving larger

impulses to the telephones, by means of the energy from the local battery released by the signal, than can be obtained from the incoming signal current itself.

The new developments in receiving make use of the fact that the wing current is of radio frequency equal to the frequency of the incoming signal, and in phase with it, since there is no appreciable lag in the operation of the ionic device. Since the wing current is of much greater amplitude than the grid circuit current, if the wing circuit be coupled to the grid circuit, Fig. 6, the current in the grid circuit can be much reinforced and give much greater variations of grid potential, causing still greater changes in the wing current. The strength of signals may be much reinforced, then, by coupling these two circuits together. Further, if this coupling be made sufficiently close, the grid circuit will be set into continuous oscillation, that is, there will be in that circuit a current of frequency determined by the constants of the circuit. Herein lies the great value of the new connections.

Continuous wave transmission has many advantages, as has been said. Simple methods of reception applicable to such waves before the new connections were known were limited to the so-called "tikker" and "heterodyne" systems. The ordinary spark receiving set, such as shown in Fig. 4 or 5, will not permit reception of continuous waves, since this receiver integrates each group of waves, each spark, into one vibration in the telephone. When a spark station sends a dot, say, several hundred sparks occur, each one with a high-frequency current discharge, but the receiving telephone receiver gets a single impulse for each spark, or train of oscillations. When there is no discontinuity in the dot, as when sent from a continuous wave station, there would be in a receiver of this kind only a single click at the end of each dot or dash The individual cycles of the high-frequency current cannot be detected, since they are of frequency beyond audibility, and further, since the telephone diaphragm could not respond to such rapid vibrations.

The tikker system of receiving permits the continuous wave to be heard by making it discontinuous at the

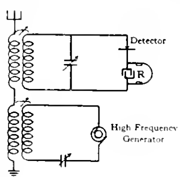

FIG. 7—HETERODYNE RECEIVER

receiving station instead of at the sending station. It is so arranged as to interrupt the receiving circuit, or to "detune" it. It thus breaks up the continuous waves into groups of cycles, which can be made to affect the telephone receiver.

The heterodyne system, invented by Fessenden, combines with the current of the received signal, a locally generated current of slightly different frequency, Fig. 7, giving a resultant current having beats, as shown in Fig. 8. This action depends upon the same principle as the familiar operation of alternator synchronizing. Therefore, although to the human ear either frequency alone is inaudible, and a telephone receiver diaphragm does not respond to either, the beats can be detected in the ordinary way by any form of detector and telephone. This system, then, requires a local source of high-fre-

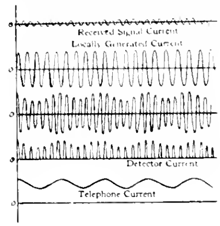

FIG. 8—HETERODYNE ACTION WITH RECTIFIER

quency current,—a generator, arc, or other means, which can easily be varied in frequency in order to receive different wave lengths, or frequencies. Variations in the pitch of the telephone sound can be made by the operator by varying the number of beats per second, by changing the frequency of the local current. The number of beats is always equal to the numerical difference between the two frequencies interacting. With the heterodyne system, interference from an undesired signal of slightly different frequency can be avoided by adjusting the beats of the undesired signal to zero or beyond audibility. The difficulty of obtaining a satisfactory source of local current, however, at first prevented commercial use of the heterodyne system. The two available methods of generation were unsatisfactory—the alternator because its frequency could not be changed easily, and the arc because its current, being slightly irregular, gave disturbing noises in the telephones, drowning out the signals. But with the discovery that the audion could be made to generate, the difficulty was swept away, and the heterodyne method became commercially feasible. The explanation of the generating action is complex, and it is unnecessary to discuss it here. However, the method is ideal for beat reception, as it gives a pure wave current of easily variable frequency. Only a very small current can be obtained from the ordinary receiving audion bulb, but sufficient output for the purpose is obtainable.

If, then, connections be made as in Fig. 6, these several actions will take place simultaneously. The audion will generate, beats will be formed in the secondary circuit in combination with the received signal current, the beats will be rectified (strictly, not rectified, but alternations in one direction being suppressed) by the detecting action of the bulb, and the resulting wing flow reinforces the grid current, increasing the strength of the signals. The audion is then acting not only as the local generator, but as a detector and amplifier at the same time. The system is exceedingly sensitive, and it

is now common for stations in any part of the country, by means of it, to hear stations of high power in Germany and Honolulu. The electromagnetic coupling of the coils $M M'$ between wing and grid circuit may be replaced by electrostatic coupling with a condenser, as in Fig. 9. The electrostatic coupling is somewhat more flexible and seems to be better, to some extent, in practical operation.

Signals can be still further amplified, by the cascade use of other bulbs of larger current capacity, to almost any desired degree of loudness. With amplifying bulbs, the wing-filament of the first is connected to the grid-filament of the second, and the wing-filament of the second to the grid of the third, etc. The addition of bulbs complicates the circuits to undesirable extent, of course, and more than one amplifying bulb is rarely used. The combination circuit of Fig. 6 strengthens also the disturbing sounds due to atmospheric discharges very greatly, and this nullifies much of the benefit of the system in regular commercial traffic. Some radio-engineers claim, therefore, that more certainty of operation, that is, less interference from strays, can be secured without the reinforcing action, using the audion only for generation of the local current and a separate audion or crystal rectifier for a detector. However, particular ways of using this general method are not yet fully established, and since the audion is a most fertile device and new features of its operation are being noted continually, we can hope for still further improvements in the direction of efficiency and simplification.

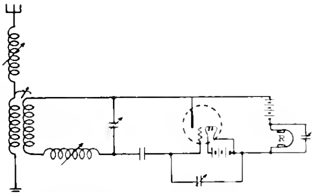

FIG. 9—OSCILLATING AUDION WITH ELECTROSTATIC COUPLING BETWEEN WING AND GRID

Improvements in the design of the bulbs are already apparent. The recent long-distance radiotelephone work was accomplished by using for the generation of the high-frequency current specially constructed bulbs, built to be capable of delivering each nearly one-half ampere. Several hundred of these in parallel gave the output necessary to transmit long distances. The design of these special bulbs has been refined in detail, and the construction is larger and better than that of the ordinary audion bulb. This design has been called the pliotron.

The advantages of pliotron generation for telephony over generation by alternator or arc oscillator is due to the fact that by it the hitherto insurmountable difficulty of control of the currents is overcome. Telephony requires modulation of the current used, in accordance with the speech vibrations, and very large currents in the antenna are necessary for long-distance transmission (one to two hundred amperes for three thousand miles, with a large antenna). With the alternator and arc generations, this large current had to be varied directly by microphone transmitters, no successful method having been found for varying the large currents by proportional changes in a related smaller current circuit, in which the microphone might be placed. Since microphones which could handle such large currents have not been built, long-distance telephony has been prevented before this time, therefore, by the lack of means for modulating the large currents, although shorter distances have been possible for many years.

On the other hand, in using the pliotron method, the difficulty was successfully overcome by using the ordinary microphone in a small current circuit, one which was arranged to vary the potentials impressed upon the grid in accordance with the speech vibrations, and therefore caused proportional variations in the large wing current. It is a relay or amplifier action, the large current variations being caused by variations in an associated small current circuit. The method works beautifully, but much development work remains to be done, for as yet the system is far from commercially feasible, since the first cost of apparatus and the care and cost of maintenance are excessive.

The point of present interest is that long-distance radiotelephony is now possible, and with the rapid advance of the radio art in the last ten years in mind, we are justified in the expectation of soon seeing radiotelephony more widely used. Radiotelephony cannot take the place of wire telephony as wire telephony is now used, but it will surely be of great use in trans-oceanic speech transmission (since submarine telephone cable signaling has been impossible) and in those fields of communication where radiotelegraphy has already proved its worth.

Recently, Mr. Alexanderson has described* a "magnetic amplifier" for controlling radiofrequency current from an alternator, which is applicable to radiotelephony, and which has worked successfully on outputs of 75 kw. This method seems to have greater immediate practicability than the pliotron method, but the eventual values of both methods depend upon the development work now being carried on.

In summary, it can be said that the greatest recent progress has been in the improvement of receiving circuits to a degree permitting reception over distances much greater than were possible two years ago. Besides this, the application of the audion generating ability to transmission, most useful in telephony, has been a great step, and may mean the introduction of a method of generation which will supersede the ones now in use. In radiotelegraph transmission, the tendency of the past several years toward the use of continuous waves is being realized by the installation of many stations of this type.

*Proceedings Institute of Radio Engineers, April, 1916.

ENGINEERING NOTES

Conducted by R. H. WILLARD
Aim—To connect theory and practice

Compensated Grades

In railway work the statement is often made that an engine hauls a train up a two percent compensated grade. A compensated grade is one in which the actual rise is less on curves than on tangent track, so that the total resistance to a train coming up the hill is constant. Grade resistance is 20 pounds per ton for each percent grade, and curve resistance is calculated at approximately 0.8 pound per ton for each degree of curvature. A two percent compensated grade would have a combined resistance of 40 pounds per ton, which, on a ten-degree curve, would give 8 pounds curve resistance and 32 pounds straight grade resistance, giving an actual grade of only 1.6 percent. Since curve resistance always acts to hold a train back whether it is going up or down, the effective downgrade in the above case would be 32 — 8, or 24, corresponding to only 1.2 percent, while the effective grade going up is 2 percent. Thus it is seen that compensated grades have different effective values coming downhill than going up, and this difference may be considerable on a crooked road.

Heat and Temperature

One of the main limitations in rating electrical apparatus is the maximum permissible operating temperature. The temperature of any body is determined by the quantity of heat (energy, not temperature) put into it and the amount of heat taken out of it. The temperature of a body is constant when the heat supplied equals the heat lost. If the supply exceeds the loss the temperature will rise, and vice versa. Heat may be supplied from outside bodies or may be generated internally. In an armature core, for instance, some heat energy is produced in the iron by the magnetic losses in the iron, some is supplied from the windings on the core (if they are hotter than the iron).

Heat may be dissipated by radiation, convection or conduction. The amount of heat (energy) radiated from a body is proportional to the difference in temperature between itself and its surrounding medium. The amount of heat dissipated by convection depends on the difference between the temperature of the hot body and the cooling medium, and also on the amount of cooling medium supplied and its thermal capacity. Heat dissipated by conduction depends on the conductivity of the path and the difference of temperature.

All these methods of dissipating heat have one feature in common,—the amount of heat dissipated increases with increasing temperature difference. Hence, when the heat supplied to a body exceeds that dissipated and its temperature rises, the heat dissipated increases till it is equal to that supplied, when a balance will be attained and the temperature will stay constant.

The gist of the whole matter is, briefly, temperature is determined by the relation between heat supplied and heat dissipated. If the heat supplied is increased the temperature can, nevertheless, be kept constant by increasing the amount of cooling medium or otherwise increasing the dissipation of heat.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1315—Series Motor Torque—Assuming that a series motor running at a certain speed requires a certain number of amperes to carry the load, will this motor exert the same torque it did while running, if the armature is prevented from turning and the current through it is limited to the same amount it required when carrying the load? W. S. (OHIO)

The torque of any motor is dependent upon the number of armature conductors, the current through the conductors and the strength of the magnetic field. Hence, in a series motor, as none of these factors are changed whether the motor is running or at a standstill, the torque developed will be the same in both cases as cited in question. However, while running the torque necessary to overcome the iron loss, friction and windage of the motor must be taken from total torque developed; while at a standstill, only the torque necessary to overcome the standing friction of armature is deducted from the total torque developed. Hence, theoretically, the actual torque that you would measure at standstill may be greater or less than that measured while running; still, for all practical purposes they could be considered as the same. J. S. D.

1316—Storage Batteries—Please furnish us with information regarding the taking of cadmium readings on storage batteries, how it is done in case of starting and lighting batteries used on automobiles, and as to what information one secures regarding the condition of battery by taking such readings. Also what is the best design of instrument for such work. We are equipped with all other instruments necessary for our work. W. G. C. (IOWA)

Cadmium readings are taken on storage batteries by using cadmium as a neutral electrode to determine the relative capacity of the positive and negative plates. Voltage readings can be taken between the positive and negative terminals and the cadmium electrode. In a normal cell the positive cadmium reading is much larger than the negative cadmium reading; so for greater accuracy the readings usually taken are the positive cadmium reading and the cell voltage. The difference between these two readings gives the negative cadmium reading. For example, if the positive cadmium reading is 2.12 volts and the cell voltage is 2.00, the negative cadmium reading would then be 0.12 volts. As a cell discharges, the positive cadmium reading decreases, while the negative cadmium reading increases. A certain battery manufacturer gives the voltage for a discharged cell as 1.95 for the positive cadmium reading and 0.25 for the negative cadmium reading; these readings give a cell voltage of 1.7 volts. On charge, the positive cadmium reading is at first greater than its cell voltage, but during the charge the cell voltage will become equal to and greater than the positive cadmium reading. When the cell is completely charged, the cell voltage should be from 0.05 to 0.10 volts greater than the positive cadmium reading. A convenient electrode for taking these readings is made from a stick of cadmium about one-quarter inch in diameter and six inches long. A rubber tube perforated with holes about one-sixteenth inch in diameter is slipped over the cadmium and allowed to extend one-eighth inch beyond the end, so that the cadmium stick cannot come in contact with the plates of the battery. A copper wire is soldered to the cadmium electrode and connected to the negative side of the voltmeter. Positive cadmium readings are taken by placing the cadmium stick in the electrolyte of the battery and the positive voltmeter terminal on the positive pole of the battery. Care should be taken to allow the cadmium to remain in the acid several minutes before the readings are taken, as considerable error may be made in the results if this is not done. As a matter of fact, a person not familiar with such tests should not place too much reliance on the results until a considerable amount of data has been gathered by means of extended tests on batteries under different conditions. O. W. A. O.

1317 — Paralleling Connections — (a) We have a 370 volt, 19.5 ampere per terminal alternator to run parallel with another machine and connected as shown in Fig. 1317(a). An engineer claimed it would give false indications Please advise if connections are right B. F. A. (PENNA.)

The synchronizing connection as shown is correct for "dark lamp" indication, that is, lamp is dark when machines are in synchronism, which is a

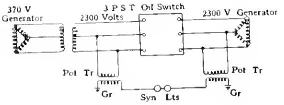

FIG. 1317(a)

standard method. However, some engineers prefer the "light lamp" method, in which case the lamp is light when machines are in synchronism. J. M. B.

1318—Reading of Static Ground Detectors—Please explain the cause of the following effect on a static ground detector connected to 2200 volt secondary bus-bars. With bus-bars and transformer bank and all distribution switches open, detectors showed zero all around. With bars alive through the bank and distribution switches still open, detectors read 6.5 divisions to Red, 0 to White and 7 to Blue. With distribution switches to underground cables closed on to the live bus-bars, detectors read 3.5 to Red, 0.75 to White and 0 to Blue. To make sure that all was O.K. the cables, bus-bars and secondary leads of the bank were tested for insulation resistance and all showed good results. All that could then be done was to calibrate the detector while connected to the live bus-bars. Is that a common practice? S. S. (SOUTH AFRICA)

It is impossible to completely answer this question with the information at hand. The reason for the performance noted might be different for different types of instrument. We should know whether the instrument is used in connection with series resistors or with condensers, and should obtain some idea as to the significance of the number of divisions mentioned. We assume that 6.5 or 7 divisions was only a small part of the full scale reading. The reading obtained with bus-bars alive and distribution switches open probably was due to a wrong adjustment of the internal vanes in the meter. These should be so spaced that when equal voltages are applied from the three-phase circuit the pointers indicate zero. The change in deflection, when connection to underground cable system was made, may have been due to variations in the electrostatic capacity of the cables. The indications of electrostatic ground detectors connected to large underground distribution systems are erratic on account of the large capacities in the distribution system. H. B. T.

1319—Skin Effect—Should the skin effect be considered when planning to use solid copper bars two inches in diameter as busses? R. B. G. (CALIF.)

The use of two-inch diameter copper rod is economical for the work. The direct-current carrying capacity is reduced to approximately 75 percent for 60 cycle and 90 percent for 25 cycle service for the same losses. The Standard Handbook, 4th edition, section 12, pp. 40 and 41, give factors for increase in effective resistance due to skin effect. In this particular case the table in the handbook is not extended far enough to cover a two-inch diameter solid rod (4 000 000 circ.mils) at 60 cycles. The coefficient for 60 cycles is approximately 1.78. The American Handbook also gives tables in a different form which give the same results. An article in the *Electrical World* of March 11, 1916, by Mr. H. B. Dwight gives a curve for obtaining the increase in effective resistance for wire or cable (which would also apply to rod) and single straps. A two-inch solid rod will carry approximately 2000 amperes at 25 degrees C. rise, with 60 cycles or 2700 amperes direct current. See also *Bulletin of the Bureau of Standards*, Vol. VIII, No. 1, 1912, pp. 172 to 181; abstracted in the American Handbook and the Standard Handbook. H. A. T.

1320—Electrolytic Lightning Arresters—The company with which I am connected uses Westinghouse Type A electrolytic lightning arresters with Type C electrolyte. The circuits are 11 000 volts, 25 cycles. We have had some trouble due to the formation of a jelly-like substance in the trays. Also on examination the film is found to be largely gone. The substations are run without a regular attendant, the electrician being supposed to see that the arresters are charged daily. The tanks are in a room in which the temperature will go to 100 degrees F. or more during the summer. I would like to know whether our trouble is mostly caused by heat or is it due to faulty charging? Would also like to know a little of what the chemical changes are. R. N. G. (KY.)

Some of the trouble may possibly be due to the lack of proper charging, but the greater part of it is due to heat, especially if the heat is long continued. The electrolyte in question will operate successfully up to 100 degrees and for short periods at a slightly higher temperature. The Westinghouse Company in their later developments have brought out a Type D electrolyte which will operate successfully up to 135 degrees, will build up the film to a higher point, and will maintain the film in better condition for a longer period of time than the previous electrolytes. The jelly-like substance found in the trays is principally alumina and water. It is a collordal form of aluminum, and is very unstable; when heated, the water will be driven off, leaving a small quantity of white residue. The presence of limited quantities of alumina has a beneficial effect. A considerable quantity of alumina in the electrolyte, as in collordal form, is detrimental to the arrester, inasmuch as it decreases the active surface of the trays. The exact chemical changes which take place are not clearly understood, but heat is undoubtedly one of the greatest contributory factors. G. C. D.

1321—Rough Slip-Rings—The slip-rings on certain generators are made of cast iron. One of the rings brings itself to a perfect polish, while the other grows dark and slightly rough. What is your explanation for this? The field current is about 130 amperes. R. B. G. (CALIF.)

Brushes of different polarity often behave differently. This roughening in many cases is due to small arcs, so that on one polarity metal vapor is carried to the brush, while on the other polarity carbon vapor is carried to the ring. This may be the explanation in the above case. See also No. 336. F. D. N.

1322—Reactors—Why are reactance coils made without iron cores? R. B. G. (CALIF.)

Reactors are made either with or without iron cores, depending upon the purpose for which they are designed. Those designed merely for the purpose of introducing impedance into the circuit, e. g., those used in connection with rotary converters for the purpose of automatic compounding, have iron cores. Those designed for the purpose of limiting the flow of current on short-circuit do not have iron cores. In the first case a given amount of reactance has to be supplied, and this can be secured more cheaply by using an iron core. In the latter case, since the purpose is to limit the short-circuit current, if an iron core were used, the induction with normal current would have to be exceedingly low in order to keep it below the saturation point on short-circuit. This would require an excessive amount of material and would make the design more costly than for an air core reactance. W. M. M.

1323—Heating of Laminations—Why is it that the laminations of electrical apparatus do not get hot when they are brought into intimate contact with the dovetail projections of stator frames? R. B. G. (CALIF.)

A magnetic circuit in electrical apparatus is laminated when it is expected to carry alternating or pulsating magnetic flux. When a magnetic field which is alternating passes into or through solid magnetic material eddy currents are at once set up in this material in a plane perpendicular to the magnetic lines. These eddy currents by Lenz' law oppose the passage of the flux and exert a damping action tending to prevent the flux passing through the solid body. Considering the case of the laminations resting against the solid dovetails, it is true that there are two magnetic paths in parallel, but as soon as the flux tends to enter the dovetails it is choked or damped out by eddy currents as explained above. In addition, the reluctance of the path through the laminations is less due to the higher permeability of the material and the presence of the air-gap between the laminations and the dovetail. The dovetail is not heated up by the damping eddy currents because the electrical resistance is relatively small and the I^2R watts are low compared to the mass of material in which they are absorbed. If, due to poor design or other reasons, the laminated magnetic circuit is highly saturated, the flux may pass into the dovetails in sufficient quantity to cause heating, but such a condition is unusual. If the laminations become connected or short-circuited at some point through which the alternating or pulsating flux is obliged to pass, serious heating may result. Such a condition might result from the rotor rubbing on the stator and polishing the surface of the stator into practically a solid sheet. A. M. D.

1324—Rewinding Induction Motor—An eight-pole, three-phase induction motor has thirty-six coils in all, or twelve per phase, one coil per slot and seventy-two slots in the machine. The twelve coils per phase are divided into four sets of three coils each. Assume that the four sets enclose the four north poles, then there are no coils enclosing the south poles, the same being true of the other two phases. The winding is a full pitch or a spread of one and two and 39 turns per coil. Now can this winding be changed to a 72 coil winding making two coils per slot and 24 coils per phase and divided into eight sets of three coils each? With three coils to every pole in place of three coils to every two poles, the winding with the 36 coils being the same as a core transformer, with a winding on but one section of the core and putting on 72 coils would be the same as dividing the winding on the one core and putting half on each core. Would it require half of the 39 turns, or 19 or 20, whichever was chosen to give the same result as the 39 did, placed say on one pole? The reason for changing is that the 72 coils can be made much cheaper than the original 36. If you can give me any information in regard to the above I would appreciate it very much. D. W. P. (WASH.)

Induction motors are usually not connected for consequent poles unless there is some special reason, such as getting a change of speed by changing the number of poles, etc. Granting that there are no special conditions of this nature not mentioned in the question, the motor could be rewound for two coils per slot and salient poles (i. e., both north and south groups) by looking out for the following condition:—In the usual arrangement, when the coils are connected for consequent poles (i. e., north poles only) the conductors are only 86.6 percent as effective on a three-phase machine as they would be if connected for both north and south poles. This is because the coils for one-phase pole are spread over twice the pole arc that they should be, or in this case the coils for an eight-pole machine are spread over the pole arc for a four-pole machine. Hence, when rewinding for two coils per slot and salient poles only 0.866×39 conductors will be required per slot if the same coil throw is kept. This equals 34 conductors per slot or 17 conductors per coil. A. M. D.

1325—Wattmeter Vibration—Will the accuracy of wattmeters be affected by a slight but incessant vibration of the switchboard panels on which they are mounted? R. B. G. (CALIF.)

Incessant vibration of the switchboard panels, even though slight, causes an increased wear on the pivots and jewels, and the accuracy will be very much affected after a time. If the period of vibration corresponds with the natural period of vibration of any of the moving elements the accuracy will be reduced more. R. T. P.

1326—Vibration of Rotor—What causes excessive mechanical vibration of the rotor of a single-phase induction motor? Would it be caused by a ground in the stator windings? J. N. K. (CALIF.)

If the reply to this question is limited to the exact implication of the question itself there are only two things which can cause mechanical vibration, namely, the rotor being out of static or of dynamic (running) balance. However, the rotor of a single-phase induction motor may vibrate under the following conditions in addition to the mechanical unbalancing:—(1) When the rotating element is eccentric with the stationary element; (2) when the rotating element is not round; (3) when there is a short-circuit in either of the primary windings; (4) a rotor of the squirrel-cage type will vibrate when there are poor joints between some of the bars and the resistance rings, causing unequal resistance in the various circuits of the rotor.

There are also certain proportions of the magnetic circuit which would cause this same condition, but the conditions mentioned above are the ones most likely to be found in a commercial machine. If the clearance between the bearing and the shaft is too great the vibration will be more noticeable. G. H. G.

FINANCIAL SECTION

THE PURCHASE OF COMMON STOCKS

The man who buys corporation bonds, notes and preferred stocks is almost always an investor making his purchases primarily for the income to be received from his holdings and not expecting, except incidentally, an advance in the prices at which he bought his securities. Of course there are at times bonds, notes and preferred stocks, more especially the latter, which partake largely of a speculative nature, but the principal appeal of the seller of these securities is to the investor and not the speculator.

The reverse is largely true of the purchaser of common stocks of corporations. He is essentially a speculator and not an investor. There are common stocks which, by reason of their long seasoning, their steady and high rate of earnings, and their regular payment of dividends over a long period, have entered into the class of investment securities, but these are far from being in the majority. It is to the common stocks of a corporation which the speculator looks for his market profits and, except under certain circumstances, the speculator does not buy corporation bonds or preferred stocks.

There are times, such as in impending reorganizations, receiverships or under some temporary corporate conditions that the speculator may find an opportunity in the bonds, notes or preferred stocks of corporations. An instance of this was recently seen in the receivership of the International Mercantile Marine. For a long period of time after its receivership the bonds of this company, on which interest had been defaulted, were selling at a low price and the preferred stock was down to but a small fraction of its par value. A speculator in Wall street casting about for some security which would offer an exceptional opportunity for profits began to look into International Mercantile Marine. He found that the great increase in ocean traffic, due to the war, had caused large increases in earnings of Mercantile Marine, and he at once began to accumulate the preferred stocks and bonds of the company. Soon it began to be noised around that the stocks and bonds were selling entirely too low and the market began to advance by leaps and bounds. The bonds went above their par value, the preferred stock sold as high as 98 and the common above 27. Several fortunes were made by the speculators who entered the market at the low figures. This shows how at times the bonds and preferred stocks of a corporation may figure largely in speculation, but these instances, as said, may be found but seldom.

Bonds and notes of a corporation are issued on actual property of value, and preferred stock of a new corporation also almost always has behind it a real value in property. On the other hand, the common stock of a newly organized corporation is usually issued for good will, for organization expenses, profits of promoters and on the future earning power of the corporation. It represents but the equities in property of the company after the bonds, notes, preferred stock and other securities senior to it have been provided for, and it is entitled to but such earnings as remain after operating expenses, interest, preferred dividends, depreciation and other charges have been met. While in the case of new corporations the common stock may have behind it no real value and be based entirely on the future earning power of the corporation, it will often be found that in the course of years there comes to be much real value behind the common stock from the building up of the property out of income, and the investment of earnings in improvements, additions and extensions. While at the time of the organization of the United States Steel Corporation the common stock of the company was entirely "water" and not based on any actual physical values in the corporation, the appropriations out of current earnings for new construction and other capital expenditures have been such that good judges now say that there has been invested in the properties of the United States Steel Corporation from its corporate income an amount more than equal to the entire amount of the common stock now outstanding. Substantially the same thing is true of other large industrial corporations of the country. While it is often charged against many large corporations that they are overcapitalized and their stocks are largely "water," it will be found that this assertion is almost always based on the

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par or face value of the outstanding stock. If the market quotations on the securities of a company under such a charge are examined it will be found, almost without exception, that the market has "squeezed" out the water, or in other words that, based on the prices at which the securities are selling in the open market, the company is not overcapitalized.

Par value, in the case of common stocks, has but little real meaning, and in recent years there has been much agitation for the issue of all common stocks without par value. In the last year a number of such corporations have been organized, largely under the laws of New York. Among these have been the Kennecott Copper, Cuba Cane Sugar, Submarine Boat, Western Power Corporation and Wisconsin Edison Company, Inc. As the common stock of a company represents only the equities in that corporation above its other securities, each share of the common stock simply stands for its proportion of this equity. If there are one thousand shares of common stock outstanding, each share represents 1/1000 of this equity, while if there are one million shares issued, each of these represents 1/1 000 000 of this equity. Under such conditions, to give a common stock a par value is often misleading, while the issue of the stock without par value, frankly representing by each share the proportionate amount of the equity of the common stock in the property and earning power of the corporation, is more and more coming into favor. The California Railroad Commission has officially approved this method of the issue of common stock, and other public service commissions have adopted the same attitude. It is probable that in the future common stocks will be more and more largely issued without par value instead of the present plan of making the stock \$100, \$50, \$25, \$10 or some other face value expressed in dollars.

In the case of public utility corporations, such as electric light and power, gas, street and interurban railways, the common stock has almost always been issued as representative of future earning power of the issuing corporation. There are some states, such as Massachusetts, where stock issues must represent actual value, but it is now being recognized that the men who invest their money in new enterprises must have an opportunity to secure something beyond a simple interest return on their investment. In general, there is hazard in any new enterprise, and if the men who furnish the capital in such enterprises were limited to a simple return of interest on the capital risked they would not be ready to risk any great amount of capital. In bringing into being and developing a new enterprise these men must find their profit in the common stock. It is to the commou stock that they look for their large return, and in the public utility field the common stocks have well repaid the faith put in them. The men who furnished the energy, brains and capital to put together the American Light & Traction Company, the American Gas & Electric Company, the Cities Service Company and other high-class public utility financing and operating groups took their compensation in the common stocks of these corporations. For some time after organization the common stocks of these companies sold far below their value, but today American Light & Traction common is selling at \$390 a share, Cities Service common at \$285 a share, and American Gas & Electric common, of \$50 par value, at \$150 a share.

There are other companies which may repeat the history of these corporations and, of course, the men who buy the common stocks of such companies when they are at a low point in their early days and hold them through the development period and on to the time of the full fruition of the hopes of the organizers will make large profits. Not all common stocks, of course, have such a successful record as those of the three companies mentioned, but there is often found an opportunity to buy at a small price the common stock of a corporation with bright prospects of future growth and progress. But the purchaser of common stocks of this class must not fall into the error that a stock is cheap because it is selling at a low price. Sometimes the most expensive common stock that can be bought is one which is selling at a low price in the market. In buying these low-priced common stocks, as careful an investigation should be made as if the purchase of a high-priced stock was being considered. Never buy a stock simply because it can be obtained for a small outlay of money. Look into the history of the issuing company, learn all that can be learned about its plants, its organization and, above all in the case of a public utility company, its prospects of expansion in its territory and of increase in its earnings.

Not long ago flamboyant advertisements appeared in the papers of a certain stock, which was heralded as "the cheapest public utility issue" on the market. This catch line was the means of securing many orders for the stock, but, in fact, while not a public utility at all in the usual meaning of the term, it was one of the highest-priced stocks in the outside market. Its par value was but \$1, and \$3 a share was being asked for it. Nothing has been heard from it for some time, and it is not probable that it will ever earn enough to pay an adequate return on its par value, let alone one on 300 percent of this par value. Now at the time this stock was being offered there were several other common utility stocks which were actually cheap at their market prices and on which the purchaser would have in the next few months realized from 50 to 100 percent increase in market value. One of these, then selling at \$20 a share, is now \$40 a share; another which was selling at \$40 a share is now above \$75 a share, and a third which was \$7 a share is now \$14 a share. There are a number of public utility common stocks now selling under \$20 a share which give promise of returning large profits to the purchaser in the next few years. One of these selling at less than \$12 a share at present is showing gains in earnings applicable to its common stocks of over 400 percent. It is true, of course, that the company is paying no dividends on its preferred stock, the latter being more than three years in arrears, but it is just because of this fact, and also that but a year ago the company was not earning its interest charges, that the common stock can be bought at the price at which it is now selling.

It is told of one of the Rothschilds of Paris that in the dark days of the Commune in Paris an investor came to him for advice regarding the investment of a large sum of money. "Buy rentes" was the advice of the great banker, thus advising the investor to purchase French government securities. "But," protested the would-be investor, "the streets of Paris are running red with blood." "That is just the reason you can buy rentes at their present price," was the rejoinder of the banker, who, by taking his own advice at the darkest time in French modern history, added millions of francs to the fortunes of his family.

There is always a reason for a low market price on the stock of a company. The factors which cause it may be only temporary or may be due to conditions which can be, or are being, removed. They may be permanent and almost certain to end in the bankruptcy of the company. In the former instance the low price of the securities will also be found to be temporary, and with the removal of these the company will return to its former prosperity and its stock advance greatly in price. In the latter the stock at any price would be dear. It is just this information that the purchaser of

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low-priced common stocks must secure. Usually he may learn the truth regarding a corporation if he is willing to take the time and trouble, and he should certainly be willing to do this where it is a case of risking his funds. If nothing definite can be learned regarding a company, then it is the part of wisdom to leave its securities severely alone.

In case you are told that a certain stock is cheap, find out just why it is selling at a low price. It may be cheap at $100 a share and it may also be dear at $1 a share. If you are convinced that it is selling at too low a price then buy it, but don't buy it until you are convinced of this fact. Many people bought the stock of the old Rock Island Company because it was selling at $1 a share and less in the face of positive information that it was not worth one cent a share, but they bought just because it was "cheap," while, in fact, it was a most extravagant purchase. When convinced that one or more of the low-priced utility common stocks, or any other class of stocks, are really cheap, buy them. Then when you have bought put them away and forget all about them. Let the company work out its future and your stocks will grow in value as the company progresses. Don't watch the daily market on such stocks, for they were bought for a long pull and not for an immediate profit. If they are worth buying they are worth holding and, unless something comes about which makes you doubtful of the future of the company working out properly, hold to them for the final result of your speculation.

Common stocks of the newly organized electric light and power companies, especially those of some of the new holding companies, look quite attractive and, where they have been properly organized and financed, with a careful selection of operating properties in growing communities, they are almost certain to show good results to the holders of their securities. The growth of the electric light and power industry has been more rapid in the last year than ever before in its history. For the first three months of 1916 there was an increase of more than 15 percent in the combined revenues of the light and power stations of the country, this combined gross being more than $107 000 000, or at the rate of over $400 000 000 a year. For March alone there was an increase of 18 percent in combined revenues and of more than 25 percent in total output of stations over March, 1915. Any industry which can show such results as these—and it must be remembered that in 1914 and 1915, when general business and industry in the United States were at a low point, the central station companies continued to report increases in revenues—is worthy of the investment of money in its securities. Electrical men say that this condition is not temporary, but that prosperity in the central station business is permanent. Under these circumstances there are no better securities, for either investment or speculation, than those of well-managed and properly financed electric light and power companies. Their common stocks are certain to increase in value, and the man who buys some of the stocks which are now selling at low prices, and are really and not apparently cheap, will find in a few years that the expansion of the business and the growth in earnings have added large amounts to the value of his holdings.

The men who are interested in the electrical industry should realize these facts and take advantage of some of the opportunities which are now available to select a list of these low-priced stocks and, making their purchases, lock up these stocks to await with confidence the future enhancement in their market value, which is as certain as it is that the business of the generating and distribution of electric current for domestic, commercial and industrial light and power is only just beginning to show the wonderful expansion of which it is capable.

So far this discussion has been largely devoted to the purchase of common stocks because of their speculative possibilities, but it must not be overlooked that there are common stocks in the market which are to be classed also as investment issues. In buying these stocks for investment substantially the same rules should be followed as in making a selection of bonds or preferred stocks for investment. The history of the company should be looked up, its earnings studied over a period of years, the obligations ahead of the common stock learned and other factors affecting the investment value of the common stock thoroughly gone over. There are companies, although not many in the public utility field, which have but one class of stock, and this stock should be treated as the same as a common stock which had preferred stock between it and the other obligations of the company. In making the purchase of the low-priced stocks for their speculative possibilities the future of the company is more to be considered than its past, while in buying for investment the past history of the company, its earnings, financing and other details are of as much importance almost as a study of its future possibilities.

It is often because a company has a bad past that it is possible to buy its stock at a low price, and it is where the company is remedying this past and strengthening itself for the future that the speculative possibilities of its stocks begin to be truly seen. But in buying for investment there should be a clean past and, so far as it may be foreseen, a clear future also.

Holders of common stocks of corporations often have rights, extra dividends, distributions of stocks, etc., which affect the market value of their holdings and return them good profits in addition to their regular dividends, and these should be carefully looked after. There are some companies which have a recognized reputation as growers of "melons," as these extra rights and distributions are often known. The stocks of such companies sell well above what would be a fair figure for the return on their regular dividends because of the fact of these extras on their stocks. Often a company has expended large amounts out of earnings for capital purposes, and has been carrying these amounts in its profit and loss surplus. Its board decides that these expenditures should be capitalized, and so a stock dividend is declared on the common stock. Again, the corporation desires to raise additional capital and at the same time give the holders of its stock something in addition to the dividends which they have been receiving. In such a case an issue of new stock is authorized and offered to the stockholders at par, although the old stock may be selling in the market well above par. Most states provide in their laws that new stock issues must always be offered first to the stockholders and if not taken by them may then be sold otherwise. The purchase of new stock at par when the old stock is selling well above that figure, of course results in a profit for the stockholders who subscribe for the stock.

Again, extra dividends on the common stock, above and in addition to the regular quarterly or semi-annual rate, may be declared when earnings have been good over a certain period. There are many ways in which the holder of the common stock of a company may profit, and this is another reason why common stocks are so popular. Some companies in the utility field, among them American Light & Traction, American Gas & Electric and Cities Service, pay, in addition to their regular cash dividends on their common stocks, regular dividends in common stock. American Light & Traction, the common stock of which is selling at $390 a share, pays 10 percent in cash and 10 percent in common stock annually. It will be seen that the 10 percent in common stock is actually a divi-

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dend if figured at the market value of the common stock of $39 a share, in addition to the $10 a share cash dividend. American Gas & Electric has been paying 10 percent in cash and 4 percent in common stock each year on its common stock. Cities Service Company limits the cash dividends on its common stock to 6 percent a year, and for this year and for 1917 will pay 6 percent annually in common stock in addition. The directors have announced that after 1917, in case earnings of the company warrant such action, this stock dividend will be increased by 3 percent each year. In paying these dividends in common stock the companies take the cash represented by the par value of the stock distributed and invest it in the operating properties, so that in effect the stock dividends are the equivalent of selling the common stock of the company to the stockholders at par. As the cash represented by these dividends in stock is invested in the physical properties of the company, the payment of such dividends is always considered as increasing the value of the preferred stock of the corporation.

American Light & Traction 6 percent preferred is selling around $112 a share, this company having followed the policy of paying part of its dividends in common stock since 1910. American Gas & Electric 6 percent preferred is selling at par under a policy of dividends in common stock since 1913. Cities Service 6 percent has not yet felt the effects of the policy, as the company will not inaugurate the dividends in common stock until September of this year. Other utility companies, as their earnings increase, are taking up this policy, so that it will be seen that there are great possibilities in the common stocks of the utility companies of the country, especially in those of electric light and power corporations, now that these latter companies are showing the largest gains in earnings in their history.

CONSUMERS POWER COMPANY OF MICHIGAN

Consumers Power Company of Michigan, the principal generating and transmission subsidiary of the Commonwealth Power, Railway & Light Company, has substantially completed its plan to take over in fee all its underlying properties formerly held through stock ownership. By this arrangement the five percent first lien and refunding bonds of Consumers Power become direct first mortgage liens on more than 75 percent of all properties of the company, and are subject only to some underlying issues on a few properties. By the carrying out of this plan several intermediate corporations have been eliminated and economies effected in operation and management, and also a direct saving in taxes. The Consumers Power bonds have had a good advance recently and are now selling close to par. Earnings of the company are showing large gains, gross for January, 1916, increasing 21.5 percent, and for the 12 months ended January 31, 16 percent, while net for the payment of bond interest increased 20 percent in January and 17 percent in the 12 months, over the corresponding periods of the preceding year. The balance for the 12 months applicable to payment of bond interest was $2 635 838, and as $1 180 178 is required for interest payments there was a balance of $1 445 660, showing that the company is earning well above twice its bond interest. Officials of the company say that not more than one percent of its increased business is directly attributable to war orders.

EMPIRE GAS AND FUEL

Empire Gas and Fuel Company of Kansas, which controls the natural gas and oil properties of Cities Service Company in Kansas and Oklahoma, has sold to a syndicate composed of Montgomery, Clothier & Tyler, J. & W. Seligman & Co., Kissell, Kinnicutt & Co. and White, Weld & Co. $14 000 000 first and collateral trust mortgage 6 percent ten-year bonds dated May 1, 1916, and with a sinking fund which will retire the entire issue at maturity. The bonds were offered at par and interest by the syndicate and quickly sold. Proceeds of the issue will be used for the retirement July 1, 1916, of the $7 000 000 five-year 7 percent notes of Cities Service Company and for the retirement of the bonds of the Wichita Natural Gas Company, the Quapaw Gas Company and other underlying liens, aggregating in all about $2 500 000. The balance of the proceeds will be used for working capital of Empire Gas and Fuel and for the development of its Kansas and Oklahoma properties. By this financing all funded and floating debt of Cities Service Company is eliminated and all earnings of the holding corporation, now totaling more than $5 000 000 a year, except the comparatively small amount required for expenses, accrue to its preferred and common stocks.

CITIES SERVICE COMPANY

Cities Service Company, which operates electric light and power, gas and electric railway properties in sixteen states, reported gross income from subsidiaries for the 12 months ended January 31, 1916, of $4 717 444, a gain of $771 849 over the preceding 12 months. Net income, available for dividends, was $4 047 168, equivalent to 2.52 times the dividend requirements for the preferred stock and, after payment of preferred dividends, equivalent to 16.26 percent on the common stock. Combined gross earnings of the subsidiary properties for 1915 were $22 656 079, an increase of $3 562 425 over the combined gross for 1914. The five-year seven percent notes of the company, of which $7 000 000 are outstanding, have been advancing in price and are now selling at 101.

NORTHERN STATES POWER OF MINNESOTA

Northern States Power Company of Minnesota, formerly the Consumers Power Company of Minnesota, has sold to a syndicate composed of H. M. Byllsby & Co., the Guaranty Trust Company of New York, William P. Bonbright & Co. and Spencer, Trask & Co. $8 000 000 of ten-year 7 percent notes, which were quickly resold to investors at 99 and interest. Northern States Power Company of Minnesota is the operating subsidiary of Northern States Power Company of Delaware, and the sale of these notes, in connection with a sale of $18 000 000 25 year five percent first and refunding bonds, which has also been made to a similar syndicate and will be offered to investors shortly, is a part of the plan for the reorganization and simplification of the financial and corporate organization of Northern States Power of Delaware and its subsidiaries. The proceeds of the notes and bonds will, in large part, be used for the retirement of the Consumers Power bonds and notes, the Minneapolis General Electric notes and the Northern States Power Company of Delaware notes which have been called for payment May 1 and June 1 of the current year, and the balance will be used for working capital.

GENERAL GAS & ELECTRIC

General Gas & Electric Company, operating electric light and power and electric railways in Pennsylvania, Ohio, New Jersey, Vermont and New York, is showing good gains in its earnings. For January, 1916, combined net earnings of subsidiaries were $94 572, a gain of $20 144, or 27 percent, over January, 1915, while for the seven months ended January 31, 1916, surplus, applicable to payment of dividends, was $135 819, or $58 236 in excess of the amount required for dividends on the preferred stock in that period. The average gain in gross earnings of subsidiaries is now running at a rate of 20 percent over a year ago. Of the revenues of the company, 66 percent comes from electric light and power, 20 percent from gas and 14 percent from electric railway service.

UNITED LIGHT & RAILWAYS

United Light & Railways Company, which has been contemplating the sale of $2 000 000 preferred stock, will not go into the market for new money at present, as its earnings have been increasing so rapidly that it does not need to raise new capital at present. The company is in the best financial condition in its history, and for 1915 gross earnings of operated properties were $6 300 000. It is believed that for 1916 gross will be close to $7 000 000. The company has no near maturities to provide for and its surplus earnings are now running at an annual rate of close to 11 percent on its common stock, resumption of dividends on which is not expected to be much longer delayed.

SMALL COMPANY'S REMARKABLE LOAD

For the first 28 days in March the Alliance Gas & Power Company made a mark of 217 530 kilowatt-hours for its day load and 205 630 kilowatt-hours for its night load, a daily average of 15 112 kilowatt-hours for the 28 days. The remarkable feature of this output is that the Alliance plant has only generating capacity of a 1000 kilowatt turbine, but a 2500 kilowatt turbine is now being installed. The general use of electric current in Alliance is shown by the fact that the per capita consumption of electric current in the little city is now $9 a year.

PERSONALS

Mr. Samuel M. Vauclain, vice president of the Baldwin Locomotive Works, has been elected a director of the Westinghouse Electric & Mfg. Company.

Prof. George C. Shaad, of the department of electrical engineering of the University of Kansas, has been appointed the Kansas representative on the Industrial Preparedness Committee of the Naval Consulting Board.

Mr. B. J. Arnold, consulting engineer, of Chicago, has been engaged by the Chamber of Commerce of Rochester, N. Y., to survey and report on the needs of the city with respect to transportation.

Mr. William von Phul, of Ford, Bacon & Davis, has been appointed to succeed Mr. Charles N. Black as vice president and general manager of the United Railroads of San Francisco.

Mr. H. G. Stott, superintendent of motive power of the Interborough Rapid Transit Company, has been retained as consulting engineer in connection with the large steam plant which the Buffalo General Electric Company is building at Buffalo, N. Y.

Mr. Edward B. Elliott, chief electrical engineer of the Sanitary District of Chicago, has resigned, and will open a consulting engineering office in Salt Lake City.

Mr. M. R. Bump, vice president of the Picher Lead Company, of Joplin, Mo., has resigned to return to the H. L. Doherty organization as chief engineer.

Mr. D. S. Miller, formerly supervisor of power and lines of the electric properties controlled by the New York, New Haven & Hartford Railroad Company, has been appointed manager of power and lines of the properties of the Reading Transit & Light Company.

Mr. D. A. Casey, who has been for the past six years machinery salesman for the Westinghouse Electric & Mfg. Company throughout the Pittsburgh territory, has resigned to organize the Service Supply & Equipment Company, with offices in the Fulton building, Pittsburgh, to act as sales agent for machinery and supplies in the Pittsburgh district.

Mr. R. H. Rathbun, formerly of Madera, Chihuahua, Mexico, and chief engineer of the Madera Company, lumbering mills and by-products manufacturers, is now connected with the stoker sales department, Westinghouse Electric & Mfg. Company, Chicago.

Mr. E. F. Bulmahn, formerly of the power division sales department, Westinghouse Electric & Mfg. Company, Chicago, has resigned, and is now connected with D. G. Fisher & Co., contracting and operating engineers, Davenport, Ia.

Lefax for May reprints the article entitled "Auto Transformers," by Mr. E. G. Reed, from the JOURNAL for March, 1916; also the article entitled "Polarity of Single-Phase Transformers," by Mr. M. A. Smith, Jr., from the JOURNAL for February, 1915.

NEW A.I.E.E. OFFICERS-ELECT

The results of the election for officers for the year beginning August 1, 1916, are as follows:—President, Harold W. Buck; vice presidents, L. T. Robinson, Peter Junkersfeld, B. A. Behrend; managers, J. B. Fisken, Charles Robbins, N. A. Carle, Charles S. Ruffner; treasurer, George A. Hamilton. At the meeting of the directors on May 16 Mr. F. L. Hutchinson was reappointed secretary for the ensuing year.

NEW ILLUMINATING ENGINEERING SOCIETY OFFICERS

The annual election of officers of the I.E.S. on June 8 resulted as follows:—President, W. J. Serrill, of the Philadelphia Gas Works; vice president representing Chicago section, M. G. Lloyd; vice president representing New England section, T. H. Piser; vice president representing Philadelphia section, G. S. Crampton; general secretary, C. E. Clewell; treasurer, L. B. Marks.

NEW BOOKS

"Mechanical Engineer's Handbook"—Lionel S. Marks. 1836 pages, illustrated. Bound in flexible red leather, handbook size. Published by McGraw-Hill Book Company, New York City. Price $5.

The German book, "Hutte," now in its twenty-second edition, has been used as the basis for this handbook. This does not mean that it is in any sense a translation, but that the editors started out to prepare a mechanical engineer's handbook, having at hand and permission to use the data contained in the above-mentioned work. The book divides itself into two main halves, the first 860 pages being devoted to the more theoretical topics, and the last 960 pages to the statement and discussion of current practice. As in other similar handbooks, a large staff of contributing editors has asisted in the preparation of the various sections, including fifty experts in all, each contributor being regarded as responsible for the accuracy of his section. The theoretical portion is subdivided into seven sections, dealing with mathematical tables and weights and measures, mathematics, mechanics of solids and liquids, heat, strength of materials, materials of engineering and machine elements. The portion devoted to practice is divided into eight sections, dealing with power generation, hoisting and conveying, transportation, building construction and equipment, machine shop practice, pumps and compressors, and engineering measurements, mechanical refrigeration, etc. The mathematical section and that devoted to mechanics is especially well handled, including a great amount of useful data in condensed form, covering practically all the ground represented in engineering courses on mathematics. The section on heat is one of the most complete on this subject that has ever appeared in the English language. Power generation is subdivided into steam boilers, the steam engine, steam turbines, condensation, internal combustion engines, gas turbines, water wheels, hydraulic turbines and cost of power. This section occupies over 240 pages. Transportation is divided into four subjects—automobiles, railway engineering, marine engineering and aeronautics. The subject of machine shop practice is covered by Mr. Alford, editor of *American Machinist*. Particularly noteworthy is the treatment of various welding processes. The section on electrical engineering covers 104 pages. In view of the very excellent handbooks available on this subject, it would hardly seem necessary to include this section in this handbook. This implies, of course, that the user will have available other handbooks, which naturally is not always the case, and is probably the reason for the insertion of a certain amount of material on this subject. However, from the standpoint of the well-equipped engineer, it would seem that this space could have been devoted to further elaboration of mechanical engineering topics. The book is unquestionably the most thorough and comprehensive mechanical engineer's handbook in the English language. The book is provided with thumb tabs to give quick accessibility to the various sections. The index is unusually complete and well arranged. Bold-face type is used judiciously to assist the reader in locating the desired topics. It has now been a number of years since an entirely new mechanical engineer's handbook has appeared, and this book will undoubtedly prove of much service to the mechanical engineering profession. A. H. M.

"The Electrical Contractor"—Louis W. Moxey, Jr. 86 pages, 15 illustrations, 49 tables. Published by McGraw-Hill Book Company, New York City. Price $1.50.

This book covers the principles of cost keeping and estimating wiring and illumination calculations and other technical problems of the electrical contractor. The writer has had some twenty years' experience in electrical contracting work and has worked out some very excellent methods for cost keeping, and illustrates a number of forms which have been found to be convenient. He also includes numerous tables giving unit labor costs for work which the electrical contractor is called upon to do. An elementary discussion is given on methods of calculating wire size for both direct and alternating-current circuits. A short discussion is also included on illumination calculation which, while quite general, should be of considerable assistance to those called upon to lay out lighting circuits.

"Electric Railway Engineering" — C. Francis Harding and Dressel D. Ewing. 416 pages; 190 illustrations. Published by McGraw-Hill Book Company, New York City. Price $3.00.

This is the second edition of this well-known textbook, planned primarily for senior technical students. In addition to revisions of the text, an entirely new chapter has been added on "Locomotive Train Haulage." This gives elementary explanations regarding drawbar pull, train resistance, speed, distance, current and power-time curves and regenerative braking. The split-phase locomotive is explained and illustrated; also a short section on the mercury vapor rectifier locomotive. The final chapter is on "Electric Traction on Trunk Lines" and gives comparisons between steam locomotives and different types of electric locomotives. Some data is also included on the cost of electrification and electric operation.

TRADE NOTES

The Westinghouse Lamp Company has moved its executive offices from 1261 Broadway to 165 Broadway, New York City.

The Standard Underground Cable Company has recently opened a new branch office at 704 Wilkins building, Washington, D. C. Mr. Edward Kerschner, formerly with the Philadelphia office, is in charge of the new office.

The C. W. Hunt Company, West New Brighton, N. Y., has issued a new valve catalogue, No. G-15-3, illustrating and describing its standard types of gates or valves for controlling the flow of bulk materials. Dimensions are given for those most frequently used in power house and storage pocket design. Copies of this catalogue will be sent on request.

The Standard Underground Cable Company has moved its Chicago office from The Rookery to the Conway building. Its Detroit office has been moved from the Free Press building to the David Whitney building. It will shortly open a new office in Minneapolis, Minn., with Mr. W. J. Weld in charge.

The Westinghouse Lamp Company has published the sixth in its series of "Electrical Salesmen's Lamp Handbooks." This issue is on "How to Design Effective Lighting." It is expected that the information contained therein will be of great value to everyone who is interested in the selling of lamps. Copies of this booklet can be secured on request to the company offices at 165 Broadway, New York City.

Mr. A. D. Fishel, who has been for a number of years in charge of the transformer division of the supply sales department of the Westinghouse Electric & Mfg. Company at East Pittsburgh, has resigned to accept the position of assistant sales manager of the Adams-Bagnall Company, of Cleveland, Ohio.

The Electric Storage Battery Company, of Philadelphia, has reprinted as their Bulletin No. 156 the article by Mr J. H. Tracy, assistant chief engineer, which appeared in the JOURNAL for January, 1916. Copies of this bulletin are obtainable from the Electric Storage Battery Company, Allegheny avenue and Nineteenth street, Philadelphia.

NEW BOOKS

"Fundamental Sources of Efficiency"—Fletcher Durell. 304 pages. Published by J. B. Lippincott Company, Philadelphia. Price $2.50.

The application of true efficiency in ordinary life and in industrial activities is astonishingly small. There are countless avenues for improvement, but the difficulty in securing proper and effective use of all resources lies apparently in the inertia of the elemental and constituent units—the labors, whether in manual or mental occupations. Before the cultivation of scientific principles becomes effective a thorough conception of all sources of efficiency must be had. Dr. Durell in these original studies has examined exhaustively and analytically into the causes of efficient attainment and presents an exposition of the contributive and fundamental factors in this important science. The eighteen chapters are headed by the following captions, which are indicative of the scope of the work:—I and II—Definitions and First Principles; III—The Unit and Its Multipliers; IV—The Group; V—Multicative Groups; VI—Orders of Material; VII—Externality; VIII—Uniformity and Diversity; IX—Expenditures and Results; X—Symbolism; XI—Directive; XII—Kinematic and Dynamic; XIII—Rythm; XIV—Dialectic; XV—Limitation; XVI—Error and Paradox; XVII—Combination of Efficients, Summary; XVIII—Applications. The book should find a fitting place in the curricula of our schools of higher education for advanced class work, but in addition may prove intensely profitable reading to students in practical life who seek a means of analyzing productive action and of increasing results through directive efforts.

E. D. D.

"Pole and Tower Lines"—R. D. Coombs. 267 pages, 161 illustrations. Published by the McGraw-Hill Book Company, New York. Price $2.50.

Committees and individuals are specializing on this branch of central station engineering and consequently a useful contribution, such as the present author has prepared, is to be welcomed. This book deals with the different types of construction and the problems involved. It is given over to mechanical considerations primarily. Costs are dwelt upon in Chapter XII. Among the prominent subjects treated in addition to loading and stresses are the quality of wooden poles, the design of steel towers and the manufacture of concrete poles. Erection methods are given. Present practice in the art is drawn upon extensively.

E. D. D.

"Five-Figure Mathematical Tables"—E. Chappell. 320 pages. Published by the D. Van Nostrand Company, New York City. Price $2.00.

In addition to the usual tables of logarithms there are included in this book tables of such quantities as the author calls "lolog," meaning the log of a log of a number; also "illog," meaning anti-log, and "illologs," meaning anti-antilogarithms. In addition, trigometrical functions and their logarithms are given in tabular form; also useful numbers and their logs and factors for converting with their logs.

"Centrifugal Pumps, Their Design and Construction"—Louis C. Loewenstein and Clarence P. Crissey. 435 pages, 320 illustrations, 8 folded insert plates Published by the D. Van Nostrand Company, New York City. Price $4.50.

The authors of this book have done a valuable work in bringing together from many sources the theory of centrifugal pumps, which has been arranged in such form as to make it most readily useful and which has been added to largely from their own experience. The first half of the book is given over to the principles of design, and formula, curves and empirical data are presented, with a complete discussion of the principles involved. Each of the parts of the pump, such as blading, guide vanes, etc., is treated separately. Especially valuable is a chapter treating of critical speeds. Almost half the book is given up to illustrations and descriptions of pumps built by typical manufacturers, together with curves of performance of many of the pumps illustrated. This part of the book should be of especial value to the user of centrifugal pumps who is seeking for information relative to the characteristics and applications rather than design data. The final chapter discusses standard methods of testing centrifugal pumps.

C. R. R.

"Electrical Engineering—First Course"—E. J. Berg and W. L. Upson. 416 pages; 296 illustrations. Published by McGraw-Hill Book Company, New York. Price $4.00.

The present textbook emanates from Union College and is designed for a college text based on the author's experience during the past eight years. The ground covered is much the same as in other similar textbooks, although the method of presentation is decidedly original. Among the topics not ordinarily included in such a work are chapters on the design of a lifting magnet, direct-current generators with commutating poles and compensating windings, theory of the ballastic galvanometer, theory and use of the wattmeter, distorted waves, hunting, combinations in multiphase transformer systems and short-circuits of alternators.

"Locomotive Operation and Train Control"—Arthur Julius Wood. 271 pages, 117 illustrations. Published by McGraw-Hill Book Company, New York City. Price $3.00.

This is a college text work based on the practice at Pennsylvania State College and refers almost exclusively to steam locomotive operation and testing, only a dozen pages being devoted to electric locomotives. Such fundamentals as tractive effort, acceleration, train resistance, predetermination of performance, etc., are gone into quite thoroughly. Probably as much data is included as is feasible in limited space, as the subject could be elaborated, giving details in a much thorough manner than is the case in this work. Considerable space is devoted to problems and questions for classroom work.

"Electrical Measurements and Testing"—Chester E. Dawes. Published by John Wiley & Sons. Price 50 cents.

This is a loose-leaf laboratory manual on direct and alternating current testing designed to be used as a manual to accompany Timbie's "Electrical Measurements" and Karapetoff's "Elementary Electrical Testing," and forms a part of the Wiley Technical Series.

"Electric Wiring Specifications"—J. H. Montgomery. 130 pages. Published by D. Van Nostrand Company, New York City. Price $1.00.

This book is intended for the use of general contractors, architects and others who are called upon to draw up specifications for electrical work. It does not include equipments of larger size or those including special apparatus. Paragraphs on various sub-divisions are numbered, and keys containing references to the various numbered paragraphs are given as the frame work for the drawing up of specifications of various kinds, such as conduit work, knob and tube work, moving picture machine equipment, etc. The final section is on illumination and on inspection.

INDUSTRIAL PREPAREDNESS MAKES BIG FIRM EXPAND

Work has been started on another big addition to the plant of the Electric Storage Battery Company, at Nineteenth street and Allegheny avenue, Philadelphia, which already is one of the largest of the kind in the country. A logical home demand for batteries is responsible for a decision on the part of the corporation officials to purchase the entire block extending from Eighteenth to Nineteenth streets and from Westmoreland street to Allegheny avenue. Mr. Herbert Lloyd, president and general manager of the Electric Storage Battery Company, in a recent interview described the projected improvements and enlargements begun by the corporation. "The Electric Storage Battery Company in 1911, already possessing the largest battery manufacturing plant in the country, anticipating a new and substantial outlet for its product due to conditions in general and the widespread usage of "Exide" battery for automobile starting and lighting in particular, erected in connection with its already extensive works a large six-story concrete building. Here was preparedness—but not preparedness enough. We had visualized tomorrow, 'but not the day after.' As a consequence, it was discovered last winter that further facilities must be provided immediately. The result of this is another six-story concrete factory, which is now under way.

"But even then our officials were not satisfied. A course of real preparedness was decided upon, a preparedness that should secure an adequate housing and facilities to meet the further demands of progress. Acting immediately, a large tract of ground was purchased. This tract extends from Eighteenth street to Nineteenth street, and from Allegheny avenue, a distance of 500 feet, to Westmoreland street. It is directly opposite our present works—a triangular plot possessing the advantage of having on its eastern front, 545 feet in length, the tracks of the Reading Railway. For years it has been occupied by two blocks of residences. These houses are now being rapidly demolished, and as soon as the ground is cleared the first of the new buildings will be erected, so that manufacturing on the new site can be started at an early date."

POLE TOP GIN

The pole top gin was especially designed to meet certain demands in the erection of steel crossarms now used so generally on wood-pole transmission lines. The original application was limited to this small field of construction, but it has since been found that it can be used on all line work where weights of any kind must be lifted and supported on wood poles, and it is meeting with considerable favor from linemen in all kinds of work. It has been found useful in handling transformers on poles either in new installations or in replacements. As an aid in general maintenance work, it means a saving of hours of labor and time. In trouble work, especially where time is such an important factor, it can effect such a shortening of an outage in the case where transformers break down and have to be replaced, as to warrant its purchase for use in only one such trouble case. It can be very satisfactorily used in replacement of poles, as it obviates the necessity of a special pole hoist and a gang of pole erectors. This pole gin, pictured in the accompanying cut, has just been placed on the market by the Railway & Industrial Engineering Company of Pittsburgh. It consists of a main base fitted with four spurs and a chain and a level for clamping it to the pole. Tackle can be suspended from the arms at the top. To attach the pole gin the lineman jabs the lower spurs into the pole, then the top of the channel is thrust towards the pole, and the upper supports sink into the wood. In this position the gin will "stay put" while the handle is opened and the chain carried around the pole and linked into the catch. The handle is then closed, causing the chain to bite into the pole. In its closed position the handle is self-locked. As the load is lifted, the lower spurs bite into the pole further and become firmly placed. This is an especially attractive feature, that is, the simplicity and ease of attachment to and detachment from the pole regardless of the load to be carried. As designed, the present gin

can safely carry a load of 2000 pounds. This capacity is ample, therefore, to handle the usual loads that are placed on the pole. As an example, a 25 k.v.a. transformer weighs 1700 pounds and a 10 kw transformer about 1000 pounds, both of which weights come within the capacity of the present design. Steel crossarms, weighing from 40 to 120 pounds, of course are very easily handled. In various other classes of work where it is customary to lash a rope to the top of the pole for hoisting purposes, this gin can be used to advantage and economically. In its original application, where a new transmission line was being built the ground man was able to hoist the steel crossarms from the ground into position at the very top of the pole, while the lineman, without the usual strenuous effort on his part, bolted the arm into place. In all line work it will relieve the lineman of heavy lifting and give the ground man more work. This results, therefore, in a greater efficiency of the line gang.

THE NORMA COMPANY OF AMERICA TO ERECT A NEW FACTORY

The Norma Company of America, manufacturers of "Norma" high-precision, anti-friction bearings, announces through its president, Mr. W. M. Nones, the purchase of a ten-acre factory site at Elmhurst, on the outskirts of Long Island City. The property fronts on Queens boulevard and has a depth of about a thousand feet, abutting in the rear upon the main line of the Long Island Railroad, from which a siding will be built directly into the plant. The company has, in five years, become prominently identified with the automobile industry of the country. Beginning as importers of bearings, the merit of its product gained quick recognition among the manufacturers of ball-bearing automobile accessories. Today "Norma" bearings are the standards in most of the high-grade magnetos, lighting generators and starting motors made in America. The steadily increasing demand for these high-speed, silent-running bearings—soon outstripping import resources—forced the company into the manufacturing field and has necessitated repeated enlargements to its factory facilities. The latest move is made in response to an imperative demand for a still larger immediate output, with facilities for extension with the future growth of the business. The plans now under way provide for a four-story building, 70 by 350 feet, to be erected immediately in reinforced concrete. Every modern improvement will be embodied looking toward the maximum of production efficiency. The architects for the new factory are Francisco & Jacobus, of New York City. The location was determined upon, not alone for the unsurpassed shipping facilities afforded, but also for its ready access to the labor markets and home sections grouped around Long Island City—surface and subway lines running close to the property giving quick communication with neighboring Long Island towns, as well as with Manhattan Island via the Queensboro Bridge.

The Ward Leonard Electric Company, manufacturers of electric controlling devices, has moved into its new building at Mount Vernon, N. Y. The increased demand for floor space and labor operators is the reason for changing. The Ward Leonard Electric Company started manufacturing electric controlling devices in Bridgeport, Conn., in 1892. After two years in Bridgeport, and three years in Hoboken, N. J., they moved to Bronxville, N. Y., and have been manufacturing in Bronxville since 1897, or for the past 19 years. Mount Vernon is nearer New York than Bronxville—as a matter of fact, the new Ward Leonard factory is 150 feet from the New York city limits.

The Richardson-Phenix Company, Milwaukee, Wis., has issued its Bulletin No. 5 on oil filters, describing a complete line of filters for purifying lubricating oil. This is undoubtedly the most complete oil filter catalogue ever issued and describes some exceedingly interesting large filters for use in purifying lubricating oil. Remarkable advances have been made in recent years in oil filtration, and scientific principles are seen in the small as well as the large filters. Copies of this catalogue may be had by addressing the company at Milwaukee, Wis.

THE CURB MARKET

ESMERALDA POWER COMPANY

No. 572 Bullitt Building,
PHILADELPHIA

List of Machinery for sale in Power Plant at Millers, Nevada

3—14x28x30 Horizontal Cross Compound Side Crank McIntosh & Seymour Gridison valve engines, water cooled journals with automatic lubrications and Richardson oil pumps for cylinder lubrication. Electric Governors.
3—250 K.W., E. M. F. 2200 amperes per terminal 65 phase, alternations 3000, speed 150, cycle 25, generator, serial 351200, 351201, 251239.

with

3—D.C. Exciters, 15 K.W., E. M. F. 125 amperes 120, Serial Nos. 355714, 30385, 355713, and necessary switchboards.
1—15x32x30 McIntosh & Seymour gridiron valve engine, water cooled journals with automatic lubrication and Richardson oil pumps and cylinder lubrications. Electric governors.
1—300 K.W. Generator, E. M. F. 2200 amperes per terminal, 65 phase, alternations 3000, speed 150, cycle 25, Serial No. 453830

with

1—D. C. Exciter, 225 K.W., E. M. F. 125, amperes 180, R.P.M. 450, serial No. 408932, and necessary switchboards.

A description of the switchboards in the plant is as follows:

2 Exciter panels with 4 D.C. Ammeters, 3 seals read 0-200 amps., 1 seal reads 0-250 amps., Serial Nos. 28936, 28053, 29040, 58722.
1 Volt meter seal D 150 volts.
4 Field Rheostats.
1 Plug for indicating voltage of 3 phase.
4 Shunts for ammeters.
4 Triple Blade duble throw knife switches 50 amps. for controlling fly wheel governor motor.
4 Generator panels with 4 ammeters, 3 scales, 0-100 amps., 1 scale 0-120 amps., Serial Nos. 32278, 33324, 33367, 58966.
Synchronizing plugs and lamps.
Ground indicating plugs.
2 Equalizing bus bars.
4 Equalizing switches 200 amperes.
4 Oil switches.
1 Total load panel with 3 ammeters, scale 0-400, Serial Nos. 33336, 333317, 32292.
1 Indicating Wattmeter scale 0-1600 E.W.
2 Type B Oil circuit breakers.
1 Distributing panel with 3 ammeters, scales 0-400, Numbers 33346, 33322, 33321.
1 Polyphase Intergrating Wattmeter No. 314157.
12 Potential Transformers 2000 to 100 Volts
2 Series Transformers 120 to 5 amperes.
6 Series Transformers 100 to 5 amperes.
2 Series Transformers 400 to 5 amperes.
2 A.C. volt meters, scale 0-3000 volts, Nos. 34197, 34198
4 Engine Gauge Boards with steam vacuum and low pressure gauge (One Board on each engine and in good condition.)
5 Style No. 30141 auto starters—5-15 H.P., 400 volts, 3000 alternations.
4 Wheeler Condensers Nos. 4050, 4055, 4054, 436. Each containing 800 sq. ft. of cooling surface.
4 Edwards Patent Air Pumps, 01424, 01425, 01420, 010459.
4 Steam Receivers.
4 Horizontal Automatic Exhaust Valves.
2—8 inch double suction Wheeler Centrifugal pumps for direct connection to 40 H.P. Motors.
1 Steel Hot Well.
1 Snow Underwriters Duplex Piston Pin Pump 14x7¼x12 No. 24359.
1 Snow Suplex Piston Steam Pump 4½x3¾x4, Number 59201.
4 Babcock & Wilcox Steam Boilers with super heaters, each containing 108 4 inch tubes 16 ft. long, 2 36″ drums ⅜″ thick x 18′ 4¾″ long. Brand O.H. Steel, 56000 lbs., 160 lbs. Pressure.
1 3″ Goubert feed water heater, 100 H.P. Boiler, nominal rating.
1 66″ steel stack 150 ft. high.
1 Barnard water cooling tower, No. 262, made by Wheel Condenser Company. With fan.
We also have for sale one Motor Generator Set.
1 Westinghouse E. & M. Co. style No. 421883 Induction Motor. Type "C" 75 H.P. 220 Volt. 25 cycle 3 phase, 480 phase, 480 R.P.M. This motor is on the same base and shaft with:
1 Direct current 50 K.W. 125 Volt, 480 R. P. M. S-421881 Generator.
Note—The motor side above was originally 25 cycles. It is rewound to 60 cycles. The Generator side is compound wound.

When any bids are accepted and sale is made, the cash must accompany the order.

RATES

Positions Vacant, Positions Wanted, Agents and Salesmen Wanted—3 cents a word—minimum, $1.50 an insertion—payable in advance.

For Sale, Wanted and all undisplayed miscellaneous ads—3 cents a word—minimum, $1.50 an insertion. Proposals—$2.00 an inch.

Advertisements in display type costs as follows for single insertions:

1-16 page,	$ 4.00	1 in. single col.,	$ 3.00
1- 8 page,	8.00	4 in. single col.,	10.00
1- 4 page,	16.00	8 in. single col.,	20.00

Contract rates on application

FOR SALE

Proposals for the purchase of 100-kw 200-kw. 400-kw. Direct-connected AC Generators offered for sale by The Panama Canal.—Sealed proposals will be received at the office of the Assistant Purchasing Agent, The Panama Canal, 24 State Street, New York City, until 2:00 P. M. July 17, 1916, at which time they will be opened in public for purchasing the above mentioned material. Blanks and general information relating to this sale may be obtained from the above office.—R. E. Rutherford, Assistant Purchasing Agent.

Engines and Generators

For sale, two 1040 H. P. horizontal cross compound, heavy duty, mill type Buckeye engines, 24″x42″x36″, 120 R.P.M., each direct connected to 500 Kw., 250 volt, Westinghouse Type "Q" generators. Excellent condition; good as new. Now in operation. If interested, write for full information and prices. Box 197, Elyria, Ohio

Save 100%

We offer for immediate shipment: 500 Kw. capacity Westinghouse Parsons turbo alternator unit, 60 cycle, 2 or 3 phase, 440 volts, complete with engine driven Exciter and Condenser; 500 Kw. 25 cycle, 3 phase, 440 volt RF type alternator for direct connection at 165 r.p.m.; 300 h.p. Smith type E Gas Producer, complete; also many A-1 units to fill practically any requirement.

Paul Stewart and Co. Cincinnati, Ohio

Meters, Transformers and Cable

Approximately 150 A.C., 60 cycle, 100 volt, Westinghouse Type OA and C house meters, three 250,000 watt General Electric oil cooled transformers, and six miles of 300,000 circular-mil triple braid weather proof cable. Address R. C. Trube, Box 625, Texas City, Texas.

For Sale

One 100 K. W. 500 volt. 275 R. P. M. Burke Electric Co. Generator and One 60 K. W .110 volt, 275 R. P. M. Burke Electric Co. Generator, directly connected by flexible couplings to Bruce Macbeth 150 H. P. Gas Engine. First class condition.

Yours very truly,

THE VAN DORN IRON WORKS CO
Cleveland, Ohio

WANTED

At Shop Repair Men—Also have position for Shop Foreman. None but most competent need apply. Our work is rebuilding of motors and generators, rewinding, locating motor or generator trouble in large plants, electric welding of rotors, repairing electric systems on automobiles, or magnetoes for boats, tractors, etc. Apply to Weil Electric Works, 821-823 Perdido St., New Orleans, La.

Electrical Engineering graduate wanted as instructor by prominent educational institution in Greater New York; at least two years experience required, either practical or teaching; salary $1,000 to $1,200 at the start, depending upon qualifications; no application considered unless full particulars are given, including training experience, age and religious affiliation. Address "Electrical Engineer" Box 197 Flatiron Bldg., New York.

Kansas City Armature Works

Electrical Machinery Repaired and Commutators Rebuilt Mining and Locomotive Armatures Rewound A. C. Windings

1920 Wyandotte Street
KANSAS CITY, MO.

FOR SALE

Engine and Generator

One 75 Kw. Crocker-Wheeler 110 Volt Generator, direct connected to Russell Automatic Engine. 265 r.p.m. Steam Separator. Lubricating Device, Switch Board and Instruments. EXCELLENT CONDITION. A BARGAIN!

ZELNICKER
WALTER A. ZELNICKER SUPPLY COMPANY
in St. Louis

Machinery Equipment Tanks

FOR SALE

1—450 H.P. Four Cylinder New Method Gas Engine, 200 R.P.M. Direct connected by coupling to 1—250 K.V.A. 3 Phase Sixth Cycles 2300 Volt revolving field, engine type Western Electric Genator. Bargain Price for Quick Purchase. Duquesne Light Company, Pittsburgh, Pa.

Generator and Motors For Sale

300 kw., type M.P., class 6, 400 r.p.m., 550 v. compound wound, belted G.E. second hand generator, and two Northern new, 20 hp., 230 v., back geared motors, normal speed 1200 r.p.m., back shaft speed 200 r.p.m. K-W Electric Co., 49 Lawrence St., Newark, N. J.

Electric Transformers For Sale

Three new Western Electric transformers, 13,200 or 6600 to 440, 2200-1100 or 550—without oil, $2,000. A. H. Cox & Co., 309 First Ave., Seattle, Wash.

Electric Light and Water Plant For Sale

Southern Indiana Town of 2000, gross earnings about $12,000, one-half cash, balance on long time at 6%. Address W. E. Daniels, Worthington, Ind.

IN TIMES OF STRESS

USE

I-T-E CIRCUIT BREAKERS

THE CUTTER COMPANY
Philadelphia, Pa.

THE ELECTRIC JOURNAL

VOL. XIII AUGUST, 1916 NO. 8

A Comparison of Distribution Circuits

In this issue of the JOURNAL appears an article by Mr. George P. Roux, which treats of the relations between single-phase, two-phase and three-phase circuits in a manner which will be readily understood even by those who are not familiar with the subject of alternating-current theory.

There are some important points, however, to which the author has not called particular attention. Although the three-phase system has a marked advantage over the single-phase system in respect to distribution, as a matter of fact it has but little advantage in the matter of transmission. This is particularly true where the transmission system is grounded at the neutral point. To understand this, reference may be made to Mr. Roux's calculations on the three-phase circuit. In these calculations he assumes the same voltage between phases for the three-phase as compared with the single-phase system, whereas for the same conditions of insulation stress, the three-phase voltage should be 86.6 percent of the single-phase voltage. Since the amount of copper is inversely proportional to the square of the voltage, it will readily be seen that, with the three-phase voltage reduced to 86.6 percent of the value used in the article, the amount of copper in each case is the same. In reality, in choosing the same voltage for the three-phase system as for the single-phase system, the author has chosen for the former a higher effective transmission voltage with correspondingly higher insulation stresses.

There are other considerations which may make the single-phase system more economical in transmission than the three-phase system, such as limitations in size of conductors on account of corona losses, but these conditions obtain only at the higher transmission voltages.

In the course of his discussion Mr. Roux makes use of the polar diagram for the representation of polyphase relations. This appears to be a convenient method of representing the currents in the circuits, but the advantages may be outweighed by disadvantages due to incorrect conceptions which are apt to be obtained. The currents in the circuits are not vector quantities but, as in the case of all periodic scalar quantities, they may each be represented by two equal vectors rotating in opposite directions at equal angular velocities. Where the scalar is a simple harmonic time-variable, the locus of each vector is a circle having its center coinciding with the center of rotation of the vector. Where wave forms other than simple harmonic are to be depicted, the loci of the ends of the vectors may be any other form of closed curve. In the vector representation of alternating currents the clockwise rotating vector is ignored and the length of the counter-clockwise rotating vector is doubled, so that the projection of this vector on the datum line gives the true instantaneous value of the periodic scaler quantity, which may be current or e.m.f. Thus Mr. Roux's diagram, if read from the point of view of the conventional vector diagram, would have a different meaning from that which he intends.

The polar diagram, while it is not ordinarily as well adapted for the representation of polyphase relations, has other very important properties, one of which is that it may be used to represent any wave form, and the area of the figures so formed will be proportional to the integral of the squares of the instantaneous values of the quantity represented. Mr. Roux's paper is of considerable interest and will prove of particular value to those who are not familiar with the theory of alternating currents.

CHARLES FORTESCUE

Derived Products

One of the most interesting features of a discovery of some new material is the manner in which it opens the way for derivative inventions. The new substance can often be used in the manufacture of many materials differing widely in their characteristics, but impossible of manufacture without the basic substance. The present dye situation forms a striking illustration of such a case. The basic coal tar products, such as benzine, toluene, etc., from which not only dyestuffs, but also photographic chemicals, explosives and other compounds are manufactured, were discovered and are still manufactured to a large extent in this country, whereas their derivative products have been developed and manufactured almost exclusively abroad.

A typical example of such a derived product is illustrated in the manufacture of noiseless gears from sheets of duck or other suitable fibrous material bonded together by the remarkable synthetic compound of phenol and formaldehyde known as bakelite. This material, described in this issue by Messrs. Lynch and Talley, is dependent for its very existence on Dr. Baekeland's discovery; and yet its characteristics and process of manufacture are entirely new.

Electrical engineering has been remarkable, more than any other branch of human endeavor, for its extremely rapid advancement. Yet a study of its history reveals that this advancement has been almost wholly by steady growth, by refined methods of design, and very seldom by the application of entirely new principles. The majority of the forward steps have been of a mechanical or chemical rather than of a purely electrical nature. Hence the development of a new and improved material for use in the manufacture of gears for use in the industrial application of electric motors may be considered as a distinct step in the general advancement of electrical engineering.

CHAS. R. RIKER

Oil Circuit Breakers and Their Application

J. B. McNeill
Switchboard Engineering Dept.,
Westinghouse Electric & Mfg. Company

FOR switching large amounts of alternating-current power and for controlling high-voltage circuits the oil switch, or circuit breaker, is the most reliable device, and is indispensable if limitation of space is a factor. This device confines all arcing to the interior of a tank full of insulating oil, thus reducing fire and life hazard. The arc is broken by inserting a barrier of oil between the contacts as they open when the voltage has dropped approximately to zero, which is the opportune moment for circuit opening.

The theory of the oil switch, that the circuit is opened when the power input is lowest, stands good

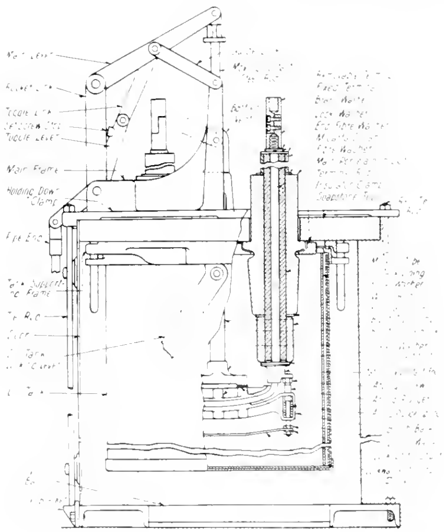

FIG. 1—MECHANICAL CONSTRUCTION OF TYPICAL OIL CIRCUIT BREAKER
Showing arrangement of parts.

today as it did twenty years ago, but the mechanical constructions used to obtain this result under different conditions are very numerous. Perhaps no line of electrical apparatus has received more attention from operating and construction men than the oil switch. Ten years ago it was not unusual for the tanks to be blown off when a heavy short-circuit was opened. The present tendency is to make oil circuit breakers more sturdy, so that they can operate repeatedly in service until inspection is convenient, and can open a circuit several times in close succession without undue distress.

In the last few years the introduction of outdoor substations and transformers has required the development of weather-proof oil switches and circuit breakers for services up to 120 000 volts, which are in every way as reliable as indoor apparatus. Up to 15 000 volts such circuit breakers are usually pole mounting, as shown in Fig. 2, and for higher voltages are either floor or frame mounted, as shown in Fig. 3. For outdoor apparatus the design must contemplate infrequency of inspection and prevention of rust, especially in bearings and moving parts.

For handling large power systems, double element circuit breakers have been successfully used. The first element cuts a suitable reactance or resistance into series with the line to limit the current and the second element mechanically interlocked with the first, then opens the circuit. Present-day practice, however, is to limit the short-circuit current by installing permanent feeder and

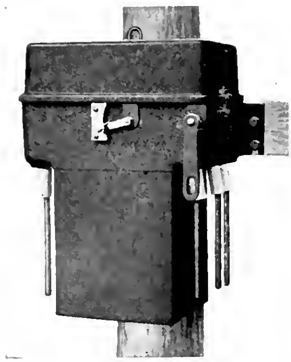

FIG. 2—WEATHER-PROOF, HAND-OPERATED WESTINGHOUSE OIL CIRCUIT BREAKER
Three-pole, single-throw, 200 ampere, 4500 volt automatic series trip type with inverse time element.

generator reactance. This scheme gives greater simplicity of circuit breaker construction.

SAFETY OF OPERATORS

Operators are now demanding fool-proof features on all switching apparatus. Small motor starting switches, etc., are made conduit connected, with all live parts enclosed. One operating company interlocks the doors of the circuit breaker structure so that the doors cannot be removed except when the circuit breaker and disconnecting switches are open. Another company has pilot lamps in the disconnect structure which light through a signal switch actuated by the opening operation of the oil circuit breaker. Still a third mechanically interlocks the oil circuit breaker and disconnecting switches so that the latter cannot be either opened or closed when the circuit breaker is in. To secure safety in operation, all modern designs have vertical gravity opening, thus eliminating the possibility of a switch accidentally dropping closed, and have both terminals insulated from the tank, as shown in Fig. 4.

ELECTRICAL QUALIFICATIONS OF A GOOD OIL CIRCUIT BREAKER

When choosing an oil circuit breaker for a given service, terminal insulation, current-carrying capacity and k.v.a. rupturing capacity should be considered.

Insulation—The present A.I.E.E. rules call for a voltage test for one minute of two and one-quarter times the circuit-breaker voltage rating plus 2000 volts between terminals and from terminals to ground. When one considers the peak voltages which may arise during lightning discharges and switching operations, this does not seem an over severe test, and many circuit breakers will stand easily three times rated voltage on test. For indoor switches the test is made dry, and for outdoor switches it is made with a water spray played on the terminals. On high-tension apparatus, sharp corners which will cause static discharges are to be avoided, as the static depreciates the insulating qualities of both the

FIG. 3—ELECTRICALLY-OPERATED, 132 000 VOLT, THREE-POLE OIL CIRCUIT BREAKER

For outdoor floor mounting.

terminal and the surrounding air. The fact is often overlooked that the presence in the air between terminals of oil gases and other conducting products of short-circuits which may be emitted from the tank may cause destruction of the switch, even though the actual voltage be only a fraction of the guaranteed test voltage. To illustrate, suppose a pole protecting a line opens when the line is grounded, the circuit-breaker pole being between the ground and source of power; as soon as the switch is open, full voltage exists between the two terminals of the pole and conducting gases may cause a short-circuit outside the tank on the line thus left unprotected. For this reason it is recommended that all terminals for 2200 volt service and above be insulated. This is usually done with tape, but micarta or fiber tubes can be used if quick assembly and removal is required.

INSULATING MATERIALS

Wood is now seldom used under oil, as it develops bad streaks even when well treated, and deposits of carbonized oil depreciate the surface. Slate or soapstone is

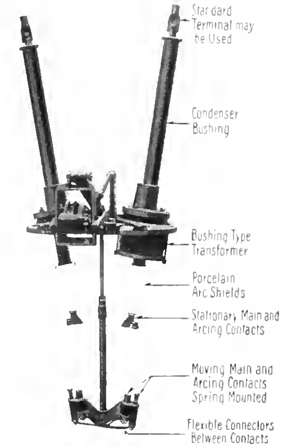

FIG. 4—CONTACT DETAILS OF 300 AMPERE, 44 000 VOLT CIRCUIT BREAKER

With butt type contacts and auxiliary arcing contacts.

used only on voltages up to approximately 600, as it develops bad streaks the same as wood and, in addition, is easily broken in machining and in service. Up to 25 000 volts porcelain or a combination of porcelain and micarta gives excellent results (Fig. 1), while for higher voltages the condenser type of terminal (Fig. 4), so largely used on high-voltage transformers, and which graduates the dielectric stress to give approximately equal voltage drops across each layer,* has demonstrated its superiority over all other types. A great advantage of the condenser bushing terminal when used

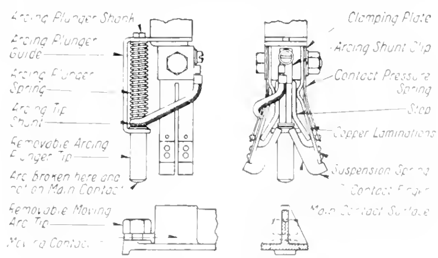

FIG. 5—DETAILS OF FINGER TYPE OF CONTACT MECHANISM

on circuit breakers is that it permits the use of small single-turn primary bushing type transformers for tripping purposes. These can be wound for small or large primary current and mounted on the frame of the circuit breaker around the terminal, but at ground potential.

*See articles by Mr. A. B. Reynders, Vol. VII, p. 766, and by Messrs. C. Fortescue and J. E. Mateer, Vol. X, p. 718.

CURRENT-CARRYING CAPACITY

The oil circuit breaker is inherently a maximum rated device, for usually it has small radiating surface and is rated at the current of rated frequency it will carry for one hour or more without exceeding the A.I.E.E. maximum temperature rise of 30 degrees C. from a room temperature of 25 degrees C. This rating is on the basis that the enclosing structure is properly

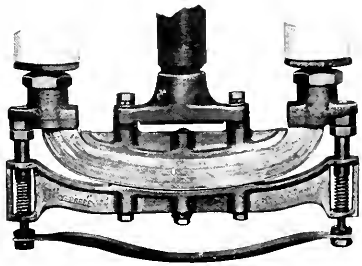

FIG. 6—DETAILS OF BUTT TYPE LAMINATED BRUSH CONTACT, WITH AUXILIARY ARCING CONTACT
Shown in closed position.

ventilated and that the connections leading away from the terminals shall not act to heat the circuit breaker. Coils permanently connected, as no voltage and overload coils, are allowed 50 degrees C. rise from a room temperature of 25 degrees C., assuming good ventilation of the enclosing space. More than rated current cannot be carried on a circuit breaker for any considerable time, as an hour, though peaks of say 25 percent overload for five minutes per hour are permissible if the normal current is not too close to the rating. Money can often be saved by noting that a circuit breaker of heavy ampere capacity will carry fully one-third more on 25 cycles than on 60 cycles.

FORM OF CONTACTS

For low ampere capacity a plain butt type contact is good, as it needs no attention except occasional inspection and is easily renewable when worn out by arcing. With this type the joint drop is small for low currents, and liberally proportioned parts conduct the heat from the joint. For high-voltage, low-current applications this contact can be supplemented by a special arcing tip which breaks contact after the main tip, Fig. 4, and by placing the contacts at angles out of the vertical line of travel a self-cleaning wiping action is obtained.

For moderate current capacities, say up to 600 amperes, the finger form of contact shown in Fig. 5 is much used. This gives a wiping action on the wedge-shaped moving contact and a positive pressure is exerted by a spring. A positive step prevents the fingers from coming too close together when the circuit breaker is open, as in that case faulty operation might occur by the moving member not engaging properly in the fingers. The chief advantage of the finger contact is that each individual finger seats itself properly and assumes its share of the load.

For heavy currents the wound laminated butt brush contact shown in Fig. 6 has demonstrated its superiority over all other forms, both for current capacity per unit of surface and for efficient wiping and self-cleaning action. The heavy pressure which can be exerted by this brush against the contact foot helps accelerate the moving contacts when the circuit breaker latch is released.

RUPTURING CAPACITY

Ability to open the circuit promptly under all conditions is the only reason for the existence of a circuit breaker. When the contacts of an oil circuit breaker open, bubbles of gas caused by volatilized oil and metal are found in the oil. A well-designed circuit breaker suppresses the arc quickly, provides oil of a high flash point, and metal or other arcing tips which volatilize with difficulty. It also provides for withstanding the pressure caused by the arc gas and for properly venting this gas without undue discharge of oil from the tank. Structurally, the opening of heavy short-circuits means speed in operation, strong tank construction and large head and volume of oil above the contacts. The rating of an oil is necessarily empirical and should be reached by exhaustive short-circuit tests.

Unfortunately there seems to be some difference of opinion as to the basis on which oil circuit breakers should be rated. Most publications list them on the basis of the amount of synchronous apparatus connected to the system, or of generators connected. When this method is used the rating is good only for one assumed case of generator reactance and short-circuit characteristic and of location and method of operation of the circuit breaker.* Generators vary widely as to the maximum short-circuit current which they will produce, and in the manner in which the current drops to the sustained short-circuit value. Again, except when the circuit breaker is right at the generator, the machine impedance, which is variable during the first few seconds of short-circuit, must be added vectorially to the impedance of lines, transformers, converters or other apparatus up to the point of short-circuit, in determining the size of circuit breaker to be used, and a circuit breaker good for 30 000 k.v.a. at the power house usually is much too large for a

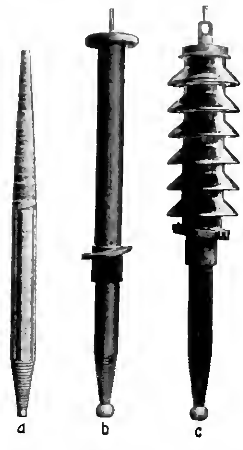

FIG. 7—CONDENSER TERMINALS
a—Terminal unfinished. *b*—Indoor type, complete with casing, clamp ring and static shield. *c*—Outdoor type complete with rain shields and clamp ring.

*See article on "Breaking Capacity Rating of Oil Circuit Breakers," by Mr. J. N. Mahoney, in the JOURNAL for Nov., 1913, p. 1103.

substation. Also, experts are not in accord as to the exact amount of power a circuit breaker rated at 30 000 k.v.a., for instance, is supposed to open. It is easily seen then that the calculation of the size of circuit breaker required for an actual case through the medium of ratings based on an assumed case is not easy.

To clear up this difficulty as to the basis of oil circuit breaker rating the Westinghouse Company has advocated a rating on the basis of ultimate or actual arc k.v.a., or the product of the current during the first cycle after the circuit breaker contacts commence to open times the open-circuit voltage multiplied by $\sqrt{3}$ for three-phase circuits. Any calculation of current from generator, line and transformer impedances necessarily omits the factor of the magnetic energy of the line. It is a matter of experience, however, that when the line on which the short-circuit occurs is in parallel with other lines of a system, the duty on the breaker opening the short-circuit is lighter than when the line is not so connected, showing that in such case the line magnetic energy is not expended in the breaker tank. In some applications the magnetic energy of the line, however, is a great factor in determining the size of circuit breaker required. The advantages of the arc k.v.a. system of oil circuit breaker rating are that it gives a rating independent of the sizes of characteristics of generators or other apparatus and independent of the location of the circuit breaker in the system. Due to increased current-limiting effect of generator and line impedances, circuit breakers can be safely rated up when used on voltages lower than their rated voltage, and in making circuit-breaker application, manufacturers' guarantees should be obtained at the service voltage to be used.

The problem of choosing a circuit breaker of sufficient rupturing capacity for a given location is, then, to determine the k.v.a. that can be delivered on short-circuit through the circuit breaker. For use with present rating tables, given in generator capacity, and based on standard assumptions,* divide the arc k.v.a. by 6.25 before using the tables.

CALCULATION OF CIRCUIT BREAKER RATING

Example of a Simple Line—Assume a three-phase feeder of No. 0 wire, four miles long, delivering 25 cycles power at 7500 volts, with 18 inches between wires. The resistance of the line is approximately 2.1 ohms per wire. The reactance on 25 cycles with the above spacing is 0.835 ohms. The impedance is, therefore, the vector sum of these values and equals $\sqrt{\text{resistance}^2 + \text{reactance}^2} = 2.26$ ohms. This is assumed to be a case of a small feeder off a large power system where a short-circuit on the feeder would not pull down the system voltage appreciably. If the short-circuit were on all phases the maximum possible current would be:—

$$\frac{volts}{ohms\sqrt{3}} = \frac{7500}{2.26 \times \sqrt{3}} = 1910 \text{ amperes.}$$

*See article on "Breaking Capacity Rating of Oil Circuit Breakers," by Mr. J. N. Mahoney, in the JOURNAL for Nov., 1913.

At 7500 volts this short-circuit capacity of the system amounts to 24 781 ultimate k.v.a. which the breaker must rupture at the contacts. Applying the reverse of the rule for determining ultimate k.v.a. from the catalog rating, this figure should be divided by 6.25, giving 3965 k.v.a. as the minimum allowable catalog rating of the circuit breaker to be applied.

Example No. 2—Assume a three-phase transformer bank, made up of three single-phase, 200 k.v.a. transformers having 3.5 percent reactance and rated at 11 000 volts high-tension and 2200 volts low-tension, feeding a 2200-volt line from a high-capacity power line. It is desired to determine the size of circuit breaker located on the feeder just beyond the transformer bank that will handle, when operated automatically, a short-circuit on the feeder just beyond the circuit breaker. Here the transformer bank is the limiting feature. The actual power that can pass through the bank is:—

$$\frac{100 \times \textit{transformer rating in k.v.a.}}{\textit{percent reactance}} =$$

$$\frac{100}{3.5} \times 3 \times 200 = 17\,100 \text{ k.v.a.}$$

The breaking capacity required is therefore:—

$$\frac{17\,100}{6.25} = 2730 \text{ k.v.a.}$$

Example No. 3—Two 18 000 k.v.a., three-phase, 8800 volt generators of six percent reactance have a bus section from which a 22 000 volt transformer bank of 2000 k.v.a. per phase and three percent reactance feeds out to a circuit breaker. What size of automatic overload instantaneous-trip circuit breaker is necessary to break a short-circuit on this feeder?

As the transformers in this problem are near the generators, the capacity of any other synchronous apparatus can be disregarded, assuming that the capacity of all such synchronous apparatus is not more than that of these generators and that they are on the line side; but the combined reactance of the transformers and generators should be included in the computations. As the reactances given are at different capacities, they should be computed to terms of equivalent reactance at the same kilovolt-ampere capacity. Thus the generators (two at 18 000 k.v.a. each) have a capacity of 36 000 k.v.a. through 6 percent reactance, and the three 2000 k.v.a. transformers through 3 percent reactance have an equivalent capacity of 36 000 k.v.a. through 18 percent reactance. The total reactance of the generator and transformers (that which governs the short-circuit current in this problem) is therefore 24 percent, with a total capacity of 36 000 k.v.a.

As in example No. 2, the actual power that can pass through the circuit breaker upon a short-circuit at this point is therefore:

$$\frac{100 \times 36\,000}{24} = 150\,000 \text{ k.v.a.}$$

It is safe to assume that an automatic instantaneous circuit breaker will trip in 0.2 seconds after the short-circuit. The voltage of a six percent turbo-generator in this time interval will drop under these conditions to

It is safe to assume that an automatic instantaneous circuit breaker will trip in 0.2 seconds after the short-circuit. The voltage of a six percent turbo-generator in this time interval will drop under these conditions to approximately 70 percent of its maximum voltage. Therefore, the circuit breaker will have to open 70 percent of 3940 amperes, or 2688 amperes per line at 22 000 volts, or 16 800 k.v.a. breaking capacity rating at the voltage. Before choosing a circuit breaker it should be noted that the voltage necessary is 22 000 volts, or more, and the ampere capacity must be at least

$$\frac{\textit{transformer k.v.a. capacity} \times 1000}{\textit{volts} \times \sqrt{3}} = \frac{6000 \times 1000}{22\,000 \times \sqrt{3}} = 157 \textit{ amp.}$$

SIMPLIFIED METHOD OF FIGURING BREAKING CAPACITY

Where the regulation of the circuit at the point where the circuit breaker is to be installed is known or can be accurately computed or measured (in case of a system already installed) the following formula may be used:—

$$\textit{Approx. short-circuit current} = \frac{(100 + \textit{percent regulation}) \times \textit{full-load current}}{\textit{percent regulation}}$$

When the percent regulation used in the above formula is the actual regulation at the point at which the circuit breaker is to be installed, taking into account the voltage drop in the generator, all transformers, the line and all other apparatus on the circuit on the power side of the breaker, the result will be correct for that whole system, for:

At no-load the voltage is 100 percent plus the percent regulation. Full-load current reduces this voltage by the amount of "regulation." Twice full-load current reduces it by twice the amount of "regulation" and so on. The current at which the voltage will be reduced to zero, that is, the short-circuit current, will therefore be:—

$$\frac{(\textit{Full-load voltage} + \textit{regulation}) \times \textit{full-load current}}{\textit{regulation}}$$

For figuring complex parallel circuits it is best to reduce percentage reactances to ohms by the rule (line volts × percent reactance = full-load current × reactance in ohms), as this method admits of easy mathematical solution.

When a circuit breaker is beyond a transformer whose capacity is not over ten percent of the system capacity in synchronous apparatus, it is safe to omit all factors except transformer reactance in figuring short-circuit current through the circuit breaker.

Bakelite Micarta-D Gears and Pinions

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DURING the steady march of modern engineering towards efficiency in all lines, a greater and greater amount of attention has been given to the losses incident to the transmission of power. It has not been until recent years, however, that noise has come to be recognized as a loss of power. And even at the present time, if the actual energy loss due to the production of sound itself were the only item to be considered, it is doubtful if it would be given serious consideration. Above everything else, however, noise indicates vibration, which is the greatest of all destructive agents, and is the red danger signal of other losses that must be considered. The direct loss of energy due to vibration has not been given much attention until recent times, but it is a factor that will have to be considered carefully as higher and still higher speeds are employed for the transmission of power.

An example of the amount of energy which may be expended in useless vibration is frequently found in a badly worn cream separator. Instances have been noted where one of these machines, which could normally be run by a small boy, could not be brought up to speed by a full-grown man on account of the vibration of the rapidly revolving bowl at its critical speed. In such a case the direct loss of energy due to vibration may be as much as 90 percent. Another noise loss which is not fully recognized is the lowered efficiency of men who are compelled to work under the unpleasant and distracting influence of objectionable sounds.

So there are two important reasons why noise should be reduced to a minimum:—first, to increase the efficiency of men; and second, to eliminate the wear and tear on machinery caused by the vibrations which produce the noise.

In the transmission of power by means of spur or bevel gears the impact of the teeth going into mesh necessarily produces a noise. The volume and character of the noise produced depends primarily on the character of the material from which the gears are made. Steel meshing with steel at high speeds produces vibrations resulting in a loud, piercing sound. Brass meshing with steel gives a less piercing sound of a lower pitch, not nearly so objectionable to those who have to work nearby. The brass, having a modulus of elasticity less than half that of steel, flexes more at the instant of impact and thus decreases the intensity of the blow.

A non-metallic material meshing with steel produces a further reduction in noise due to the very low modulus of elasticity of this material. Non-metallic material, however, in order to be suitable for gears, must have a mechanical strength sufficiently high to withstand the stresses involved without increasing the width of the face of the gear to abnormal limits. It must be hard enough to wear well and must not shrink or swell from

oil or moisture nor deteriorate in storage. The teeth of a gear should be able to withstand the service requirements without metallic reinforcement of their ends, so that the two mating gears can be made of equal width of face in order to obtain uniform wear over the entire wearing surfaces of both.

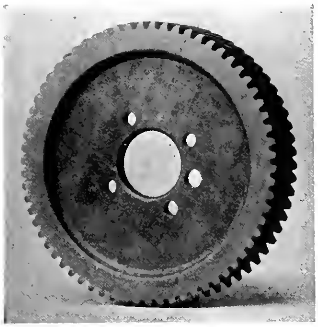

FIG. 1—BAKELITE MICARTA-D TIMING GEAR FOR AUTOMOBILE IGNITION
Cut from solid blank; no metal end plates or rivets used.

A substance which meets the requirements of a successful non-metallic gear material has recently been developed under the trade name "Bakelite Micarta-D." It is a product of heavy duck bonded together with Bakelite by heating while under an enormous pressure. It is as strong as cast iron, is unaffected by atmospheric changes, is vermin-proof, and can be stored indefinitely without shrinkage or other deterioration. It can be operated in oil without any signs of swelling. It is self-supporting, and in most cases neither bushings nor flanges are required. Wherever the requirements are unusually severe, or where the diameter of the gear is several times the width of the face, end plates may be advisable, but even in these cases the teeth need not be shrouded and the width of the gear is determined only by the power to be transmitted. In non-metallic gears formerly used in which the teeth are shrouded, it is necessary to make the width of the face of the non-metallic material equal to the width of face of the mating gear plus the aggregate end play of both

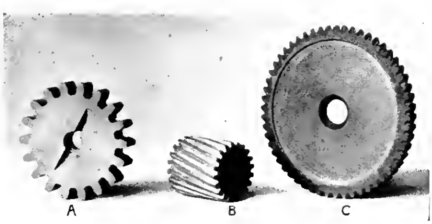

FIG. 2—BAKELITE MICARTA-D GEARS
A—Speedometer gear. *B*—Helical pinion. *C*—Helical auto-ignition gear. All cut from solid blocks without metal plates or rivets.

shafts; otherwise the shrouds will mesh and the gears will be noisy. In order to fulfill this condition it is necessary to specify a greater width than would be necessary to transmit the required power. This is unnecessary with Micarta gears; in fact, it is advisable that the width of face of these gears be made the same or less than the mating gears in order to insure uniform pressure over the entire tooth. Because of this fact Micarta gears are used in many special applications where the use of any other non-metallic gear would be impracticable, such as a two-inch face pinion meshing with a seven-inch face flywheel, etc.

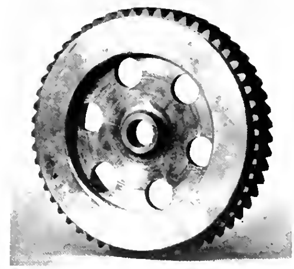

FIG. 3—BAKELITE MICARTA-D TIMING GEAR
One-piece metal center, with micarta face of the same width as that of the mating gear.

PHYSICAL PROPERTIES

The following physical properties of Bakelite Micarta-D have been determined by careful tests:—

1—Tensile strength, parallel to laminations—10 000 lbs. per square inch.

2—Compression strength, perpendicular to laminations—35 000 lbs. per square inch.

3—Compression strength, parallel to laminations—17 000 lbs. per square inch.

4—Transverse strength, maximum fiber stress parallel to laminations—17 000 lbs. per square inch.

5—Transverse strength, maximum fiber stress perpendicular to laminations—17 000 lbs. per square inch.

6—Co-efficient of expansion per inch per degree Centigrade—0.00002 inch in the direction parallel to the laminations and 0.000085 inch in the direction perpendicular to the laminations.

7—Specific gravity—1.4.

8—Weight per cubic inch—0.05 lb.

9—Shrinkage is practically zero up to a temperature of 100 degrees C.

10—Oil absorption—practically zero.

11—Water absorption—0.25 to 2 percent by weight, depending on the relative amount of edge surface exposed (with 50 hours' immersion in water at 21 degrees C.)

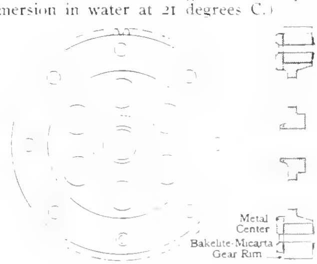

FIG. 4—DETAILS OF GEAR SHOWN IN FIG. 3

MACHINING

Bakelite Micarta-D machines readily and takes a good polish. It machines best at high speed and with plenty of rake to the tool. It can be machined in any direction and drills and taps readily. The same tools

are used as for steel when cutting teeth, but an increase in cutting speed of 25 percent and an increase of feed of 50 percent may be used. When cutting gear teeth the blank should be supported at the back to prevent the fraying of the edges when the tool comes through. For turning, a speed of 400 to 500 feet per minute with a tool having a 30 degree cutting angle and 10 degree clearance will be found very satisfactory.

DESIGN OF GEARS

The effective thickness of Micarta material between the root of the tooth and the bore should be not less than the depth of the tooth. At present Micarta-D plate is not made in thicknesses over two inches. Hence when gears having a face of more than two inches are required two or more plates must be riveted together, using metal end plates or standard washers under the rivet heads. Metal end plates made of free cutting steel should be used for gears of 2.5 pitch and heavier and for finer pitches when the pitch diameter is over four times the width of the face. These end plates should be such as to prevent their meshing with the mating gear, either by extra width of Micarta to prevent interference ,or by turning off the end plates to the roots of the teeth.

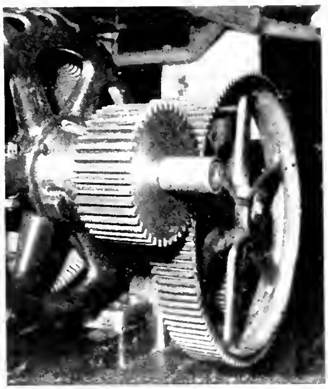

FIG. 5—BAKELITE MICARTA-D PINION
Mounted on 100 hp, 480 r.p.m. induction motor connected to a high-pressure pump.

Gears may be keyed to the shaft in the usual way when the ratio of the pitch diameter to the width of the face of the gear is four or less, provided the length of keyway is not less than the width of face. However, in some cases where the teeth are relatively coarse it may be necessary to reinforce the hub with metal plates or bushings in order to provide strength and rigidity. In fact, the thickness of the end plates is governed almost entirely by the torque at the hub. Where the torque is light the chief function of the end plates is to serve as washers, and in such cases end plates one-eighth to one-quarter inch will be found satisfactory. Where the torque at the hub is heavy the end plates must also serve to strengthen the keyway. In such cases the end plate should be one-quarter to three-eighths inch thick, and in extreme cases end plates should be in the form of flanged bushings.

Automobile timing gears can usually be made from solid Micarta plate. In case it is necessary to have a web gear, in order to allow for clearance, it is preferable to use a metal hub and web, only the teeth and rim being made of Micarta.

Spur, bevel, spiral and helical gears can be made from Bakelite Micarta-D. They should be used in mesh with metal gears, and in order to operate satisfactorily both gears must be cut true, lined up accurately and properly spaced between centers. The allowance for back lash should be about double the usual allowance for steel.

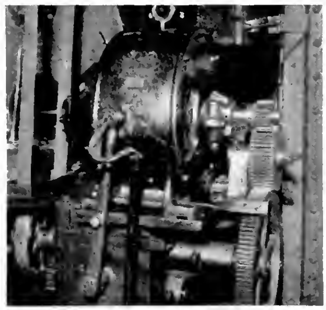

FIG. 6—BAKELITE MICARTA-D INTERMEDIATE GEAR
Driven by a steel pinion on a 10 hp, 780 r.p.m. induction motor connected to a vertical boring mill. Metal end plates not cut back.

Lubrication of Micarta gears is essential. Any good lubricating oil or grease will be satisfactory, but there should be plenty of it. Rough or worn teeth of mating gear or bad alignment will cause vibration and rapid wear.

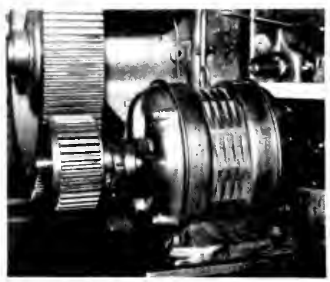

FIG. 7—BAKELITE MICARTA-D PINION
Mounted on 7.5 hp induction motor driving punch press. Pinion face narrower than face of mating gear; metal end plates cut below root of tooth.

APPLICATIONS

Bakelite Micarta-D gears can, in general, be substituted for steel (untreated), cast iron or bronze gears and

with the same dimensions as the metal gears which they are to replace. It is understood, however, that the maximum fiber stress, with proper factor of safety, must conform to the physical properties previously given. If full end plates are used the Micarta must be wide enough to allow for end play; where the end plates do not extend beyond the root of the teeth, no extra width of face is necessary.

The long life of Micarta gears has been proven under the most severe service conditions and in a large variety of applications, such as timing gears for automobiles, main driving gears for punch presses, boring mills, engine lathes, pressure pumps, crane motors, textile machinery and general machine shop service. Accurate records of these gears have shown that, when properly applied and lubricated, they will outlast rawhide or other non-metallic materials previously used for gears, and in certain classes of service will outlast cast iron. This means a decrease in annual cost, together with a quiet running gear.

Regenerative Braking with Polyphase Induction Motors

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Regenerative braking of electrically-driven trains has given desirable results in railway work. Especially is this true of locomotives equipped with polyphase induction motors. The control is simple and no additional connections are necessary except in cases where a voltage adjustment is desirable. The method by which such braking is accomplished may be explained as follows:—

To drive a locomotive the induction motors must furnish a turning force, which must balance the pull of the train, and also the frictional losses in the bearings and driving rods. To overcome a given resisting torque an induction motor revolves at a certain speed. If this load is reduced the motor speeds up. When all the load is removed the induction motor runs at nearly synchronous speed, the internal losses and friction reducing the speed a little. Synchronous speed depends on the number of poles and frequency; for a large number of poles this speed is low, and for a small number of poles, high; for a high frequency the synchronous speed is high, and for low frequency, low. Mathematically, the synchronous speed in r.p.m. equals 120 times the frequency divided by the number of poles.

If an induction motor is to run faster than its no-load speed, a turning effort foreign to the machine must be applied, and tests show that practically as much turning power must be applied to run the motor a given number of r.p.m. above synchronous speed as the force which the motor will overcome when running as a motor at the same number of r.p.m. below synchronous speed. The slight difference between these two conditions is due to the internal losses of the motor. When running as a motor, delivering power, the motor must overcome its own internal losses and friction; but when driven above synchronous speed the driving force must overcome the machine friction and losses.

When voltage is applied to the windings a current is induced which sets up a magnetic field, and this field travels from one pole to the next and on to the third at a rate of one pair of poles for each cycle. If, for example, the motor has eight poles, it will take the magnetic field four cycles to go completely around the motor. At 25 cycles per second, or 1500 cycles per minute, the magnetizing field will travel completely around the machine 375 times in a minute, or will make 375 r.p.m.; while if the motor has four poles at 25 cycles per second, the field will rotate at 750 r.p.m. This is the synchronous speed. The primary can be considered as a rotating magnet with a north and a south pole revolving on the shaft at 375 r.p.m. If the rotor winding is closed on itself, either short-circuited or through the rheostats, and is standing still, the magnetic field in rotating will cut these conductors, setting up a voltage therein, which induces a current in each rotor circuit, and these currents create a magnetic field in the rotor to oppose the motion of the rotating primary or main magnetic field. Obviously, the less resistance there is in the motor circuit, the more current will flow for a given induced rotor voltage, and the greater the rotor flux will have to be to oppose the magnetic field. This opposing rotor flux, or field, tends to move the coils along with the main rotating field so as not to be cut by it, and results in causing the rotor to revolve. The greater the rotor flux, the more the rotor will tend to revolve, because the turning force is thereby increased. Then, as the rotor coils speed up in the same direction as the rotating magnetic field, the conductors are being cut by the flux less rapidly until at the time when the rotor turns as fast as the rotating magnetic field, and in the same direction, there will be no voltage induced in the secondary windings. For this condition the rotor must run at synchronous speed. However, the friction and losses in the machine hold down the speed of the motor slightly, so that some current must flow in the rotor coils to set up enough field in opposition to the main rotating field to drag the rotor along against these losses, overcoming them. Then, too, with resistance and reactance in circuit, enough voltage must be generated

to force the required current through the wires, making it necessary that the rotor run at slightly lower speed than the rotating magnetic field.

If a train is pulled by induction motors there will be a speed at which the force of the rotor flux, opposing the magnetizing flux, is just great enough to balance the losses in the motors and the force required to pull the train. Again, if some of the cars are uncoupled, the motor will have less work to do and will speed up a little. Railway induction motors are so designed that when running with the rotors short-circuited a small change in speed makes a big change in the opposing rotor flux. When the train starts downhill the force of gravity will move the train ahead by its own weight, and will reduce the force required from the motors, the speed increasing until the motor runs free at synchronous speed. Beyond that point the train tends to drive the rotor faster than the rotating field. When this occurs the rotor conductors are again cutting the rotating magnetic field, since they are revolving faster than

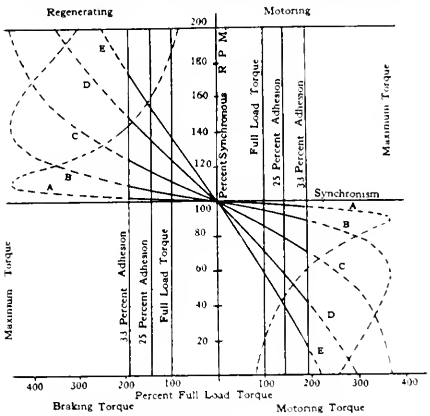

FIG. 1—RAILWAY INDUCTION MOTOR CHARACTERISTICS

A—Rotor short-circuited
B—Rheostat resistance = 3 × rotor resistance
C—Rheostat resistance = 9 × rotor resistance
D—Rheostat resistance = 19 × rotor resistance
E—Rheostat resistance = 29 × rotor resistance

synchronous speed. The rotor flux set up opposes this tendency and tends to bring the rotor speed back to that of the magnetic field and, in so doing, resists the force of gravity acting to run the train downhill. The faster the train moves, the more resisting force the motor exerts until its opposing force equals that of the train, then the speed becomes constant.

As stated above, if for a given speed the resistance in the rotor circuits is high, less current will flow in the windings than when the coils are short-circuited. So in motoring, to get a large torque or turning effort at a low speed, such as starting, resistance is inserted in the rotor circuits by means of a rheostat, for the slip or difference in speed between that of the rotating magnetic field and that of the rotor must be considerable so as to generate enough voltage in the rotor circuits to force the required current through the windings and resistance inserted therein. Then to force a given current through the windings, a higher voltage must be induced to overcome the resistance of the circuits; and to induce a higher voltage the difference in speed between the rotating magnetic field and the rotor must be greater. As the motor speeds up, requiring less turning force, this resistance is cut out. Similarly, in regenerating or braking a train, in order to allow the train to speed up, resistance is put in the circuit. This is also done to "catch" the train at high speed; then its speed is brought down nearer to synchronous speed by cutting out resistance. This gives a large torque at all the speeds from the highest down to synchronous speed.

In Fig. 1 the relations of speed to torque are shown by curves, the full lines showing the working range of each curve. Curve *A* is that of the speed for a railway induction motor in which the rotor is short-circuited. Here a small change in speed brings about a large change in the torque of the motor, and likewise the same condition obtains in regenerating. It will be noted that in regenerating the maximum or pull-out torque is about 120 percent of the maximum or pull-out torque in motoring, due to losses in this motor. Curves *B*, *C*, *D* and *E* show the effect of bringing the resistance of the rheostats into the rotor circuits. The rotor must run at a relatively low speed to get maximum torque on curve *B*, while on curve *C* the maximum torque occurs when the motor is standing still. However, if this value of resistance were used the wheels would slip, because the torque is greater than the adhesion of the wheels to the track will take care of.

Curve *E* is the best one for starting, for with this value of resistance in the rheostats the greatest possible torque is obtained just at start and is gradually reduced as the motor speeds up. By cutting out some of the resistance the torque curve changes to *D*, *C*, *B* and *A*, respectively, and the motor gives greater torque at the higher speeds until the rotor is short-circuited. Then as the force of gravity on the train going down grade tends to run the motor faster than synchronism, the torque increases in the opposite direction, and tends to hold the speed down. In regenerating, as resistance is cut out, the resisting torque of the motor is reduced for the speeds just above synchronism, and the train runs faster until the resisting motor torque and the effect of gravity balance, so that any train velocity above synchronism may be obtained by manipulating the resistance in the rotor circuits.

From the foregoing it is evident that a motor cannot regenerate below synchronous speed. However, on two-speed motors, running speeds can be maintained on down grades at slightly above each of the synchronous speeds, thus providing a slower speed for heavy trains and a faster speed for passenger or light freight trains.

Some of the unique features of regeneration with polyphase induction motors which cannot be obtained by steam locomotives:—

1—A constant train velocity up or down grade without change of motor connections.

2—Air brakes are required only to stop or hold the train.

3—Power developed by a train on a down grade helps haul other trains.

The Cost of Generating Power*

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THE subject of power generation is a very broad one, which must be studied from both the financial and economical viewpoint. In any power generation problem the cost of power is made up of two main items, fixed charges and operating charges, which in many steam plants are very nearly equal. Fixed charges are made up of interest on capital, amortization of capital, functional depreciation, taxes and a portion of administration expenses or running expenses chargeable to the cost of power. Operation and maintenance costs include all costs of operating the plant and maintaining it at normal efficiency.

Unfortunately the element of fixed charges is often neglected or ignored in computing and comparing power costs. When you operate a trolley car you do not simply include the platform labor and the maintenance of the roadbed, track, etc., but you have to go back and see what the money costs you. You have to buy money just as you buy cable or anything else. You cannot get money for nothing; no one will lend money without expecting interest on it.

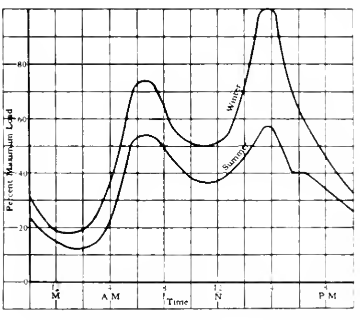

FIG. 1—TYPICAL DAILY RAILWAY LOAD CURVE

WHAT CAPITAL WILL COST

The first item to be determined in fixed charges is what the money will cost you, considering interest and providing for the return of the money to the one you borrowed it from. The latter is called an amortization charge and is usually included in with interest, resulting in a total cost for the money of about six percent. Taxes form a larger percentage of the total cost of power than is often realized, amounting to something like 3.5 percent on the total investment, varying from two to five percent. By the time you have included all the items in fixed charges you will find that it will cost you not less than 10, and probably 12 percent or more, for the money you have invested.

In hydraulic plants the condition is quite different, for the operating charges are so small as to be negligible, while the fixed charges are usually high.

The curves given in this article will serve to illustrate many points regarding the cost of power. Thus a typical daily load curve of a large railway is shown in Fig. 1, the lower curve being typical of summer conditions and the upper curve for winter, when the extra power required for electric heating and the heavier schedule result in a greater power demand. In this particular case the heating amounts to 20 percent of the load schedule.

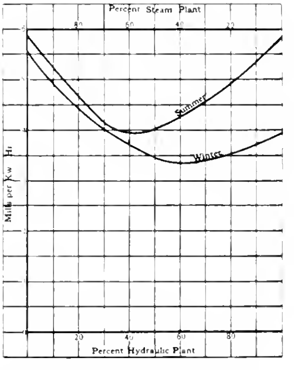

FIG. 2—TYPICAL SUMMER AND WINTER CURVES
Showing average cost of power, steam and hydraulic plant.

Assuming a given daily cost of power as in Fig. 1, a comparison is given in Fig. 2 of the cost of power derived in varying proportions from a steam and from an hydraulic plant. It may be seen that, under the typical conditions assumed, there is a certain combination of steam and hydraulic service that will result in the lowest power costs. For railway work it is almost invariably found that such a combination results in lower costs than power from either a straight steam or hydraulic plant.

In Figs. 3 and 4 summer and winter load conditions have been analyzed to show the hourly cost of power for each hour of the day, for a number of combinations of steam and hydraulic power supply. It will be seen that the curve of cost of power goes up as the load goes down; that is to say, if we analyzed the cost of power for twenty-four hours we would find that it reaches a maximum during the small hours of the night. The dif-

*Revised from an address before the Connecticut Company Section of the American Electric Railway Association, and published in *AERA* for June, 1910.

ference between the cost at 3 A. M. and 9 A. M. is very marked. The first or *A* curve is all hydro-electric power, and shows how the cost goes up enormously at certain hours in the night, which indicates that you cannot afford to run an hydraulic plant on light loads. The *B* curve shows the cost with 75 percent hydro-electric

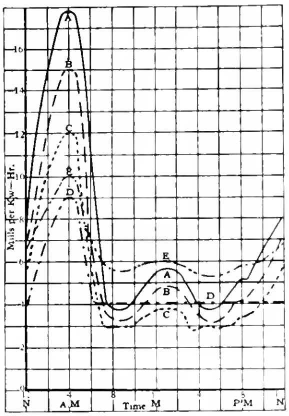

FIG. 3—COST OF POWER DURING DAY—SUMMER LOAD
A—100 percent hydraulic— 0 percent steam.
B— 75 percent hydraulic— 25 percent steam.
C— 50 percent hydraulic— 50 percent steam.
D— 25 percent hydraulic— 75 percent steam.
E— 0 percent hydraulic—100 percent steam.

power, and 25 percent power from a steam plant, the curve *C* being 50–50, and *D* represents all steam power.

FIXED CHARGES AND COST OF LIGHT LOADS

The variations in the cost of power with load factor, of one plant costing $60 per kilowatt and one costing $80 per kilowatt, are shown in Fig. 5, the lower

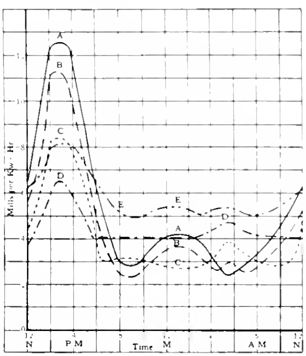

FIG. 4—COST OF POWER DURING DAY—WINTER LOAD
A—100 percent hydraulic— 0 percent steam.
B— 75 percent hydraulic— 25 percent steam.
C— 50 percent hydraulic— 50 percent steam.
D— 25 percent hydraulic— 75 percent steam.
E— 0 percent hydraulic—100 percent steam.

curves plotted below the zero line being the operating and maintenance costs. The first curves above the zero line show how important fixed charges or investment costs become at light loads. As the load factor increases the fixed charges become less and there is also a decrease in operation and maintenance cost. At any load factor the total cost of power can be obtained by adding the two ordinates, as represented by the upper curves

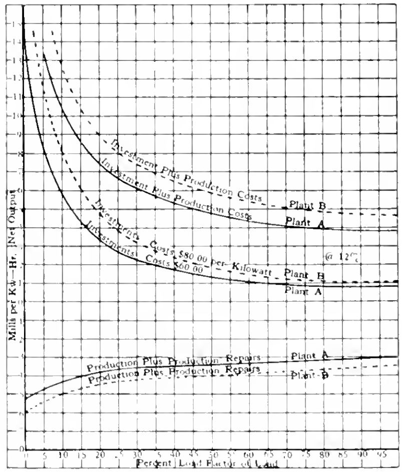

FIG. 5—VARIATIONS IN COST OF POWER WITH LOAD FACTOR

above zero line. This shows how important it is in any plant to build up the load factor.

Referring to the upper $80 per kw curve it will be seen that at 50 percent load factor the total cost of power is about one-half of what it is at 20 percent load factor.

Typical load curves for the $60 and $80 per kw plants are given in Fig. 6, operating at 45 and 25 percent load factor, respectively, the idea being to illustrate what

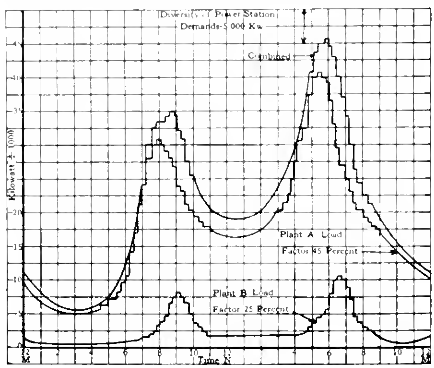

FIG. 6—COMBINED LOAD CURVE FOR LARGE AND SMALL STATION
Plant A—$60 per kw, 45 percent load factor.
Plant B—$80 per kw, 25 percent load factor.

would happen when the smaller load is added to the large one. Suppose you had a small direct-current station and shut it down and took the load on to another plant which already had a fairly large load. That introduces another factor, sometimes called the diversity

factor, but I do not think that describes it very well. "Time differential" is a little better description. It is simply this, if you can find a load to add on to your other load, whose peak load or high point does not come at the same time as your other load, then you can carry the second load with advantage without adding much to the capacity of your plant; in other words, the fixed charges will not be increased by adding the load in the valleys as long as you do not add it to the higher peak. The difference between the broken line and combined curve at the peak represents the time differential, and 5000 kilowatts in total capacity of the plant would be saved by having this small load added; in other words, if you have a 5000 kilowatt plant in one place, and a 50 000 kilowatt plant in another place, and could take the small load and add it to the large load, without making the peak 55 000 kilowatts, it would pay you to shut down the small plant.

TYPICAL FIRST COSTS

The average installation of hydro-electric plants at the present time in first cost will amount to not less than $150 per kilowatt of capacity. You can put up a first-class steam plant today, depending on the size, varying from about $55 to $75 per kilowatt capacity. That is considerably less than half of the hydro-electric plant. If you have to build a big dam to give you large storage of water, then the hydro-electric plant may run from $200 to $250 per kilowatt of capacity. The other difficulty with the hydro-electric plant is that there are usually certain dry seasons, one or two months in the summer, or maybe in the early fall, when your hydro-electric power will be cut down largely, so that now it is becoming pretty well recognized that as an investment the hydro-electric proposition must be considered very carefully. The reason for this is the uncertainty of water supply, unless you go to enormous expense for dams and storage. These questions exist even in such water supplies as furnished by the Niagara river.

The writer came in contact with a case some months ago in a consulting capacity where a large company not very far from Niagara Falls was confronted by two conditions; first of all, they were not allowed to get any more power from the Falls. The governments of the United States and Canada had established a certain maximum number of cubic feet per second which they will allow to be diverted from the Falls. They have now reached that point. The business of this company kept on growing at a very rapid rate, and the question was,—What is the best thing to do? After making a thorough investigation of the shape of the load curve, and an analysis of the whole situation, and taking into consideration what power is costing them now, it developed that they could afford to put in a large steam plant of their own and make power at least as cheaply as they could buy it at Niagara Falls. That, of course, is conditioned on the load factor; that is to say, if the load was going to last more than twelve hours a day the hydro-electric power would be the cheaper. If the load lasted less than twelve hours a day, the steam power would be the cheaper. The result of the investigation is that this company is now building a plant which will cost $4 000 000, so as to make the greater part of their own power.

If such a condition exists at Niagara Falls, where they have ideal conditions, you can imagine what would exist at the average water power plant, which runs dry half the time. There has never been known to be a lack of supply of water at Niagara Falls.

When we talk of cheap hydro-electric power, there is a string attached to it. It is cheap, of course, when you consider the cost of running the water power, when you get it going, because there is little labor, practically no material to be supplied, as the water runs into turbines and makes the power. That is very simple, but as pointed out before, you cannot get the money for nothing, you have got to pay for the money; instead of paying for coal or other supplies that you do pay for in a steam power plant, you have to pay in this case for the money, pay interest, and provide an amortization fund, in connection with the money that you borrowed with which to build the plant.

So we find that for practically all cases where the load is that of a lighting company or a railway company, which means that the load factor is not more than 50 percent, and in some cases goes down to 30 percent, water power is a very questionable investment, and it would have to be looked into very carefully to find out whether the total cost of that power would not be greater than you could make it from a steam power plant.

SIZE OF PLANT AND COST OF POWER

The size of plant has quite an appreciable effect on cost of power. Below certain sizes of steam generating units, in the case of the modern turbine, the efficiency goes down very rapidly, below about 1000 kilowatts. In such cases it would be better to buy a reciprocating engine, direct connected to your generator, than to put in turbines. As the size goes up, however, the turbine shows considerable improvement over what the reciprocating engine can do, and when we get to units of 30 000 kilowatts or more there is a very marked improvement. The unit purchased not long ago by the company with which the writer is connected is going to give 70 000 kilowatts, on 10.5 pounds of steam per kilowatt-hour. Further, there must be a certain number of men around to take care of the station, engineers, firemen, oilers, etc. A man can take care of a large unit almost as easily as he can take care of a small unit, so that the cost of help does not go up in proportion to the size of the plant. That is another thing which makes a large plant cheaper; but with a very large plant the cost of these items is almost negligible, and the cost of coal and water are very important things, especially the cost of coal.

For illustration, when we started developing power for the electrification of the Manhattan Elevated Railway System in New York, about fifteen years ago, it

took almost three pounds of coal per kilowatt hour, and today we are making power for 1.5 pounds of coal per kw-hr. with modern turbines. The difficult situation which has arisen has been a financial one. When the old units were put in they were the finest units every built. They cost a very large amount of money, but owing to the progress of development of the steam turbine, which offered such large improvement in economy, it seemed advisable to take out the engines and replace them with the turbines. Those units cost approximately a quarter of a million dollars, and when we took them out and scrapped them they were worth about $10 000. How are you going to write off the difference? These are some of the problems in financing which do not appeal to the average person, because they do not run up against them: but it is a real problem, a perfectly honest one, because money was paid for the units fifteen years ago, they were perfectly good to operate, had high economy for their time, but to get better economy they were taken out and sold for scrap and replaced with turbines. That touches the question of what we might call the effect of obsolescence upon the economy of production.

ADVANTAGE OF DIVERSIFIED LOADS

The general question as to whether the railway company should manufacture its own power or buy it is a very interesting one. If we look at the thing from its broadest aspect, there is no reason why a railroad company cannot build just as economical plants as any power company can. The only difference is the one pointed out in Fig. 6, where, if you can combine several different kinds of loads with your own railway load, then you get what you might call a time differential; in other words, you fill up the hollow in the load curve without adding anything to the investment. Suppose there was 50 000 kilowatts capacity, which the railroad required only at certain times. If you could sell power to some consumer who would come in and fill up the valley in the railway load, such a valley as is shown in Fig. 6, then you could sell your power for a very low rate, as you have not added anything to the fixed charges. It would, at the same time, cut down your own cost, as you would certainly expect to make a profit on what you sold.

The flatter your curve, that is, the more you can fill up the valleys, the cheaper you can manufacture the power. That is the main object in the general power company going out and getting loads from all sources, various kinds of loads, and especially night loads. If you can build up a load factor as good as the power company can, then there is no reason why the railroad company should not make the power and sell some of it to some one else. If the power company can build up a better load curve than you can, then they can make power cheaper than you can make it.

Effect of Brush Width on Commutation

C. G. Lewis

THE SIZE of the brushes on direct-current motors and generators is a very important consideration, as the brushes have a very important effect on the commutation, and commutation has a very important bearing on the life and upkeep of all direct-current machines. Therefore, what seems like a very small matter, viz., the width of the brush, or number of bars covered by the brush, is a point that has a large influence on the operation of direct-current machines, and is the deciding factor in the operation of some of them which happen to be designed very closely.

The commutating zone of a direct-current motor or generator is the zone on the armature surface in which the armature coils are undergoing commutation, or in inches it is the distance which a point on the armature surface travels from the time that the first armature coil side in a slot pitch starts to commutate until the last coil side has completed commutation. This commutating zone is a very important quantity. It is equal to,—

$$P_t \frac{C_s + B_1 - k + C_h}{C_s} \qquad (1)$$

Where P_t = tooth pitch in inches.
C_s = number of commutator bars per slot.
B_1 = number of commutator bars covered by the brush.
k = a constant depending on the type of winding.
C_h = number of commutator bars which the armature coils are chorded.

If there are three commutator bars per slot and the brush covers only one commutator bar it would take three commutator bar pitches for all the coils in one slot to complete commutation in case of a multiple-wound armature if the armature were pitch wound. If the brush covered two bars the commutation would be completed in the space of four commutator bar pitches or, still assuming that there are three commutator bars per slot and the winding is not chorded, 1-1/3 slot pitches. Therefore, in a multiple-wound armature which is pitch-wound, commutation of all the coils in a tooth pitch is completed in the space of the number of commutator bars per slot, plus the number of commutator bars covered by the brush minus one. In a two-circuit winding where the number of commutator bars is not divisible by the number of pairs of poles, instead of subtracting one from the number of commutator bars per slot plus the number of bars covered by the brush subtract 0.5 bar in a four-pole machine and 0.66 bar in a six-pole machine and so on. The term k in equation (1) then equals 1 for a multiple-wound machine, 0.5 for a two-circuit, four-pole machine; 0.66 for a two-circuit, six-pole machine, etc. Still assuming three commutator bars per slot, if the winding is chorded one-fourth of a slot, then $C_h = 0.75$. The expression,—

$$\frac{C_s + B_1 - k + C_h}{C_s}$$

gives the number of tooth pitches it takes for all the conductors for one slot to cut across the slot flux.

What has been called the reactance voltage is the voltage generated in the zone of commutation in the coils which are undergoing the process of commutation by the flux, which is produced by the armature magnetomotive force. The reactance voltage may be said to be made up of the voltage generated in the short-circuited armature coils by three fluxes—the interpolar flux, the flux cut by the end windings of the armature coils and the slot flux. The latter is the flux produced by the magnetomotive force of the armature winding, which extends from the tooth top across the tops of the slot and teeth, the whole of this flux being cut by the conductors undergoing commutation. The expression for the voltage generated in the short-circuited armature coils by the slot flux* is,—

$$\frac{I_c\, W_t\, T_c\, R_s\, \pi}{10^8}\left(\frac{L}{s}\quad 1.33d_s + 0.52 + 2.10s\sqrt{n}\right)C \qquad (2)$$

It can be seen from this that the slot voltage is directly affected by the value of the constant C_3. The value of this constant is,—

$$\frac{C_s}{C_s + B_1 - k + C_b}$$

and therefore, to increase the width of the brush, B_1, is to decrease the voltage generated in the short-circuited armature coils by the slot flux. It will also increase the width of the commutating zone. The part of the reactance voltage due to the slot flux is generally the largest.

Assume, for instance, a four-pole motor the brushes of which cover three commutator bars. Suppose, also, there are three commutator bars per slot and the armature coils are chorded one-fourth of a slot, then the constant C_3 in formula (2) is,—

$$C_3 = \frac{C_s}{C_s + B_1 - k + C_b} = \frac{3}{3 + 3 - 0.5 - 0.75} = 0.48$$

Now suppose that the brush were changed and that the density were so low that a brush could be used which only covers two commutator bars. Then,—

$$C_3 = \frac{3}{3 + 2 - 0.5 + 0.75} = \frac{3}{5.25} = 0.571$$

Or the value of the e.m.f. due to the slot flux will be 19 percent greater.

Assume now that the armature coils undergoing commutation have only the circulating currents in them caused by the short-circuit voltage generated in the coils as mentioned above. The magnetomotive force produced by these coils is represented by Fig. 1. The heavy line represents the first case and the light line the second. This also gives an indication of the short-circuit voltage generated in the coils, since it is this voltage which produces the local currents referred to. The heavy line represents a much better condition from the standpoint of good commutation, because the maximum value is lower and the maximum value is not as much greater than the average, as is the case with the curve given by the light line. It is, therefore, easier to make the face of the commutating pole the correct shape and, as can be

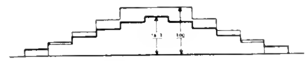

FIG. 1—MAGNETOMOTIVE FORCE CURVE PRODUCED BY ARMATURE COILS UNDERGOING COMMUTATION

Heavy line represents case where brush covers three commutator bars. Light line represents case where brush covers two commutator bars.

seen, the instantaneous variations will not be so large. In the case of the dark line the commutating pole will have to have a wider face. The maximum value increases about 21 percent when the brush width is decreased from the width of three bars to two bars.

In general, good commutation cannot be obtained if the voltage generated in the armature coils short-circuited by the brushes exceeds four to five volts per coil. Suppose a motor is just on the edge as regards commutation. It has been designed and built so that none of the other quantities given in formula (2) can be changed without some trouble and expense. If the brush width is increased, the value of the constant C_3 is decreased and, therefore, the short-circuit voltage per coil is also made smaller. This may be just enough to bring the value of the short-circuit voltage per coil within safe working limits.

When a motor has a high short-circuit voltage, it is generally necessary to make some refinements in the details of design, because the variations from the average volts generated in the short-circuited coils to be equalized by the commutating pole are very often too large, unless the face of the pole is carefully shaped to take care of them. The strength of the commutating pole is made sufficient to generate a voltage equal and opposite to the average reactance voltage per coil, but if, due to the high maximum voltage per coil, its strength is not sufficient to counteract the voltage in the middle of the commutating zone and is too strong for the voltage

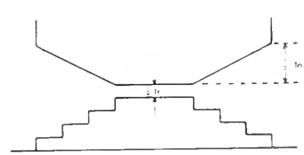

FIG. 2—MAGNETOMOTIVE FORCE CURVE AND COMMUTATING-POLE FACE WHICH ARE NECESSARY FOR NEUTRALIZATION

just at the edges of the zone, sparking will result, even though the total voltage across the brush is kept down to safe working limits by the action of the commutating poles.

When the brush width is increased the width of the commutating zone is also increased, and if this is carried

*From a paper on "A Theory of Commutation and Its Application to Interpole Machines" in the *Transactions A.I.E.E.*, 1911, Vol. XXX, p. 2386, in which

I_c = current per conductor.
W_t = total number of wires on the armature.
T_c = turns per individual armature coil.
R_s = revolutions per second.
S = width of slot, assuming parallel sides.
n = ratio of width of armature tooth to the width of armature slot, at the surface of the core.
L = width of armature core, including ventilating spaces.
d_s = total depth of slot.
C_3 = correction factor for the brush width, chord winding, etc.

too far the brush will short-circuit some of the armature coils when under an active field, due to the fringing of the main field flux. If this happens it is almost impossible to make the machine commutate properly, and the only thing to do is to make the brush narrower.

The commutating poles should cover approximately the width of the commutating zone, so the width of the brush cannot be increased beyond a certain limit on this account. When the commutating pole is not wide enough it does not sufficiently compensate for the short-circuit voltage generated in the armature coils on the outside edges of the commutating zone. Therefore, there will be local currents which may cause sparking and heat the armature coils above normal.

The width of the commutating pole and zone can be determined from formula (1). The shape of the field which it has to neutralize is shown in Fig. 2 and, therefore, the commutating-pole face should be the inverse of the curve shown. If, therefore, the air-gap in the middle of the pole is one-eighth inch, the air-gap on the edges of the pole should be approximately one-half inch, since the strength of the field to be neutralized is four times as great in the center of the pole as on the edges.

It can also be seen from Fig. 2 that if the commutating pole is correct for the brush width that gives the magnetomotive force curve shown, it may not be correct for a narrower or wider brush, since the shape of the magnetomotive force curve is changed.

The brush would have to be wider the fewer bars there are on the commutator in order to cover the same number of bars. However, it is generally necessary to make the brush wider as the number of bars is increased, in order to keep the same width of commutating zone. For instance, in an armature with 61 commutator bars and 8 turns per armature coil, 31 slots, a one-fourth inch wide brush, 7.25 inch diameter armature and a 5.12 inch diameter commutator the width of the commutating zone in inches will be from formula (1),—

$$\frac{0.762\ (2 + 0.95 - 0.5 + 0.5)}{2} = 1.125$$

If the combination is changed to 81 bars, 6 turns per coil, 41 slots, a three-eighth inch wide brush will be required in order to obtain approximately the same commutating zone. A three-eighths inch wide brush covers 1.84 bars. Then from formula (1),—

$$\frac{0.556\ (2 + 1.84 - 0.5 + 0.5)}{2} = 1.07 \text{ inches.}$$

The combination might be changed again to 81 bars, 6 turns per coil, 27 slots, and the width of the brush would then have to be only one-eighth inch to obtain practically the same commutating zone. A one-eighth inch brush under these conditions would cover 0.628 bars or, from formula (1),—

$$\frac{0.845\ (3 + 0.628 - 0.5 + 0.75)}{3} = 1.09 \text{ inches.}$$

It should not be understood from the above, however, that the brush width could be increased indefinitely, and thereby commutating conditions made better, for the limit of the allowable total volts across the brush is reached. Approximately two volts across the brush uncompensated for is permissible with fairly good commutation. If without the commutating pole there is eight volts across the brush, the allowable departure from exact compensation is 25 percent. If, however, there is 16 volts across the brush normally, the voltage will have to be compensated for within 12.5 percent. Therefore, it is necessary to be sure that the total volts across the brush does not rise to too high a value.

When the brush width is changed the brush position, or neutral, is also changed. The amount that the brushes will have to be shifted is equal to half the change in the brush width.

The Compensated Generator

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Heavy peak loads, high speeds and difficult operating conditions for direct-current machines necessitate the neutralizing of the distorting effects of the currents in the armature winding in order to secure good performance characteristics. The method of obtaining this result is to slot the pole faces of the field cores and place a winding in these slots which is connected in series with the armature. The number of conductors in the pole faces is proportioned so as to neutralize the armature conductors covered by the pole face. The excess winding necessary to produce a commutating flux is concentrated on the commutating poles, located midway between the main poles.

Such a machine is known as a compensated machine because of the special compensating or balancing pole face winding, the function of which is to compensate for or balance the armature reaction, or in other words, to neutralize the magnetizing effect of the armature winding. It is therefore placed as near to the armature winding as possible, and the more uniformly this winding is distributed about the periphery or space surrounding the armature the more perfectly will its chief function be performed.

Generally speaking, direct-current generators and motors may be classified under three main heads, referring to their commutation characteristics:—1—non-commutating pole; 2—commutating pole; 3—compensated. All three types have a similar armature, shunt and series field construction. The commutation features constitute their principal difference. The non-commutating-pole generator has no provision for a flux to produce commutation, except as is brought about by

shifting the brushes. But with the commutating-pole machine and the compensated machine special provision has been made for producing a commutating flux. In these two cases additional poles are placed between the main poles, which are smaller than the main poles and are magnetized by conductors which are connected in series with the armature, so that the magnetizing effect is proportional to the armature current.

The principal feature distinguishing the commutating-pole machine from the compensating machine is

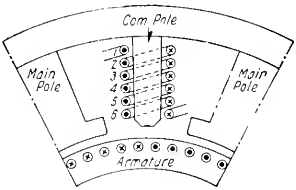

FIG. 1—MAIN AND COMMUTATING POLE OF A COMMUTATING-POLE MACHINE

Showing all magnetizing conductors concentrated about the commutating pole.

the winding of the conductors which neutralize the armature reaction and magnetize the commutating pole. With the commutating-pole machine all the conductors are wound around the commutating poles, as shown in Fig. 1. With the compensating machine some of the conductors are located on the commutating poles, while the rest are distributed in the main pole faces, Fig. 2, where they can more completely neutralize the effect of the armature magnetization and prevent the distortion of the flux under the main pole.

In large current machines this winding usually consists of a number of copper bars embedded in slots in the main pole faces and lying parallel to the armature conductors. As can be seen in Figs. 3 and 4, these bars are connected in series and in series with the armature, so that any change in armature current involves a corresponding change in the current on the compensating winding.

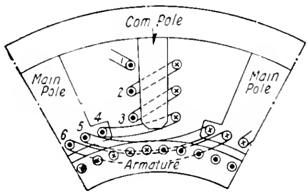

FIG. 2—MAIN AND COMMUTATING POLE OF A COMPENSATED MACHINE

Showing part of magnetizing conductors placed on the commutating pole and part distributed in the main pole face.

To secure a clear understanding of the benefits of a compensating winding it is necessary to know how the voltage is distributed about a commutator and how the maximum voltage between two adjacent commutator bars is affected by the armature reaction and how this maximum voltage is affected by the compensating winding, since the maximum voltage between commutator bars is one of the limiting features of direct-current machines.

If, for example, the voltage between two adjacent commutator bars becomes excessive, an arc may be established between them, and this arc may give rise to a flashover.

FIG. 3—COMPENSATED GENERATOR

Showing magnetizing conductors embedded in main pole face.

Flashing between brushes or other mechanical parts consists in the formation of an electric arc, similar to the arc formed in an arc lamp. It takes a high voltage to form an arc through air, and therefore in an arc lamp it is found necessary to first bring the carbons into contact with each other, and subsequently draw them apart. After the arc has once been established a comparatively small voltage will maintain it, because the metal and carbon vapors between the electrodes are very much better conductors than air.

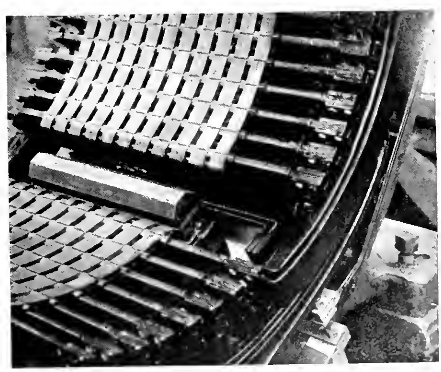

FIG. 4—COMPENSATED GENERATOR

Showing strap conductors about the commutating pole and distributed in the main pole face.

Hence the first means to avoid the formation of an arc at the brushes is the improvement of commutation, and the introduction of commutating poles and compensated windings has helped very materially in eliminating sparking and consequent flashing. The minimum voltage which will cause flashing depends on several factors,

hence there is no fixed value which can be stated as a limit for all machines. At the same time, any element which inherently increases this voltage is undesirable, and any means of neutralizing this effect without otherwise impairing the usefulness of the machine is desirable. Hence the introduction of the compensated-wound machines is another stage of the evolution of direct-current design. Such machines may be made to meet unusually severe requirements.

The armature reaction has a quite different effect in each of the three types of machines. In the non-commutating-pole machine, armature reaction distorts both the main flux and the commutating flux; in the commutating-pole machine it distorts only the main flux, and in the compensated machine it distorts neither. The resultant effects of these distortions produce in the machines certain characteristics which determine their suitability to perform different classes of work. The commutating flux, or flux between the main poles, determines to a large degree the operation at the brushes,

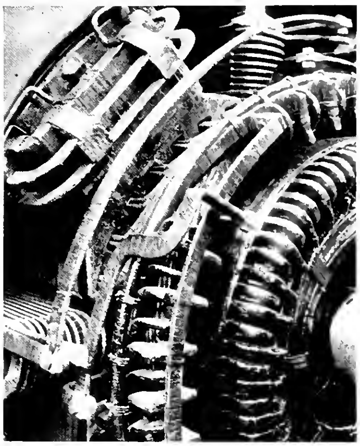

FIG. 5—COMPENSATED GENERATOR
Showing commutating-pole windings and the conductors distributed in main pole face.

while the main flux under the main poles determines the voltage characteristics and also the voltage between adjacent commutator bars, which may have much to do with the operation under heavy loads.

As the commutating flux for the non-commutating pole machine must come from the main poles, and as this flux does not increase as the load increases, it follows that it is necessary to shift the brushes with the load if the best results for commutation are obtained. Hence flashing may be experienced if the brush shifting is not affected.

Brush shifting is not necessary on either the commutating-pole machine or the compensated machine, since a flux for commutation is produced by the commutating poles midway between the main poles, which varies automatically and directly as the load, because the same current passes through the armature and the commutating-pole windings. The fact that non-commutating-pole generators require that the brushes be shifted, while the second and third class do not require any shifting, constitutes a difference in armature reaction, because with the brushes in the neutral position the reaction from the armature tends to establish a field which would pass through zero at the middle of the main pole piece and be a maximum between the main poles, tending only to distort the main flux. However, the armature reaction in non-commutating-pole machines with the brushes shifted has two effects, one tending to distort the main flux, which is a cross-magnetizing effect, and the other directly opposing the main flux, which is a demagnetizing effect, and is proportional to the amount of shift of the brushes.*

By fixing the brushes so that the coil under commutation lies midway between the main poles, which is the proper position in both commutating-pole and compensated machines, the demagnetizing effect of the armature is avoided, and on account of the absence of the demagnetizing effect of the armature such machines require less compounding. Hence the armature reaction in a commutating-pole machine has a cross-magnetizing effect, but not a demagnetizing effect. This cross-magnetizing effect tends to distort the flux under the main pole, the most serious effect of which is to increase the maximum voltage between commutator bars. This effect may be of serious consequence if the average voltage between commutator bars is already high.

The main benefits of the compensated winding are that it prevents, under sudden changes of load, the main flux from sweeping across the pole face; in other words, prevents a distortion of the main flux, thus lowering the maximum voltage which would otherwise obtain between adjacent commutator bars. Furthermore, it decreases the amount of leakage which is present when all the windings are concentrated on the commutating pole. It is evident that the leakage is very much reduced, when one considers that the leakage is mainly between the main pole tip and the commutating pole, and that the magnetomotive forces producing this leakage are very much less because a large proportion of the conductors are located in the main pole face. For all these reasons, heavy overloads such as are found in roll-mill service, can be carried most satisfactorily on the compensated generator. The superiority of this type of machine is especially noticeable in the case of high-speed motor-generators and machines for roll-mill and hoist service, particularly when both generators and motors are subjected to very high peak loads. Such loads are usually of short duration and consequently do not generate much heat in the windings, but the commutating conditions are exceedingly severe.

*See article on "Armature Reaction," by Mr. R. H. Taber, in the JOURNAL for January, 1914, p. 65.

Interpretation of Test Data

SINGLE-PHASE SQUIRREL-CAGE INDUCTION MOTOR

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When testing induction motors, it is advisable, and often necessary, to have a reliable method whereby part of the test data may be used to check the rest of the test data; or for various reasons it may not be possible to make a complete test on the motor, and yet the designer must be certain that the motor meets the requirements. A reliable and accurate method of obtaining the characteristics of a single-phase squirrel-cage induction motor from the locked and running saturation data, together with the resistance of the main and starting windings, is described below. For convenience in reference, a one-half horse-power, 60 cycle, single-phase, 110 volt, four-pole, no-clutch motor is used as an example.

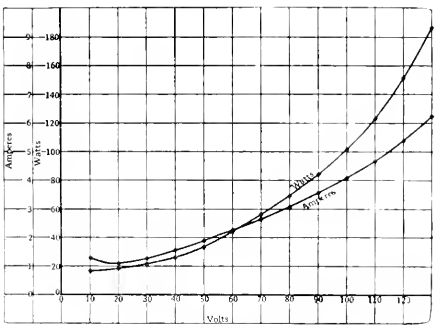

FIG. 1—RUNNING SATURATION CURVES OF SINGLE-PHASE INDUCTION MOTOR
Resistance—Starting winding = 3.92 ohms, cold.
Resistance—Main winding = 1.07 ohms, cold.

TESTS

Running Saturation Curve—Data for this curve is obtained by measuring the volts, amperes and watts at various voltages from 120 percent rated voltage down to the lowest voltage on which the motor will run. These tests are taken with the motor running light, and should be made at the normal operating temperature of the motor. From this data two curves can be plotted, as shown in Fig. 1, using amperes and watts as ordinates and volts as abscissae. The friction and windage loss is considered as the lowest point on the watt curve, although, if greater accuracy is desired, the primary copper loss at this voltage should be subtracted from the wattmeter reading. If the friction and windage loss is already known, only one running light reading is required, and that should be taken at rated voltage, with the temperature of the motor at the normal operating point.

The Locked Saturation Curve is obtained by taking three or four readings of volts, amperes and watts with the rotor locked, at voltages which will give current values around the full-load current of the motor. The values for the rated voltage may then be calculated, since the current varies directly as the voltage and the watts vary as the square of the voltage. The averages of the current and watt values at rated voltage are then taken as the true locked values at rated voltage and, if desired, curves can be drawn through the observed values and continued to the calculated values at rated voltage, as shown in Fig. 2. Where refinements are not required, one locked reading at a voltage which will produce full-load current will be sufficient.

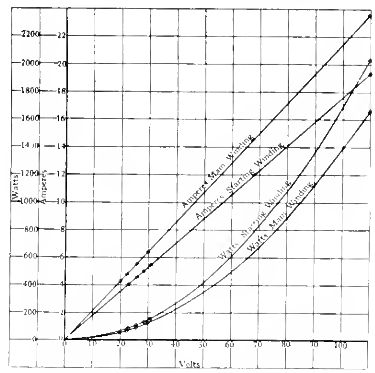

FIG. 2—LOCKED SATURATION CURVES OF MAIN AND STARTING WINDINGS

The object of taking these locked readings at low voltages is to overcome the effect of heating, because a normally-designed motor will heat rapidly when locked at rated voltage; hence such readings are of no value unless taken the instant after the switch is closed and, since the meter pointers do not settle instantly, it is impractical to take accurate locked readings at rated voltage.

The Resistance of the main and starting windings should be measured with a Wheatstone bridge or a Kelvin balance, depending upon the numerical value of the resistances, and should be measured cold. The temperature rise on the primary copper of a normally-designed motor, running at full load, is approximately 35 to 40 degrees C., and, therefore, the hot resistance of the main winding is approximately 115 percent of the cold resistance. More accurate results are obtained by measuring the cold resistance of the main winding and then

adding 15 percent, than by measuring the hot resistance directly. In the case of the starting winding, experience has shown that 25 percent should be added to the cold resistance of the starting winding to obtain the hot resistance. The reason for adding a greater percentage in the case of the starting winding than in the case of the main winding is due to the fact that the circular mils per ampere is considerably less in the starting winding than in the main winding. The cold resistances are given with the running saturation curve, Fig. 1.

The main winding test data required for calculating the values which are used in constructing the performance diagram are given in Table I. From this data the reactance, secondary resistance locked, secondary resistance running, magnetizing amperes main field and iron loss must be determined in order to draw the performance diagram. These values in inches can best be

TABLE I—SYMBOLS FOR TEST DATA AND PERFORMANCE DIAGRAM

E	Rated voltage	110.	Volts*
i_o	No-load current, main winding	4.66	Amp.*
i_L	Locked current, main winding	23.5	Amp.*
i_{LS}	Locked current, starting winding	19.3	Amp.*
i_m	Magnetizing current, main field	2.52	Amp.
P_o	No-load watts	122	Watts*
P_L	Locked watts, main winding	1655	Watts*
P_F	Friction and windage loss	17	Watts*†
P_i	Total motor iron loss	63	Watts
P_m	Iron loss due to main field $= P_i \times 0.55$	35	Watts
P_c	Iron loss due to cross field $= P_i \times 0.45$	28	Watts
P_{LS}	Locked watts, starting winding	2025	Watts*
P_S	Secondary copper loss, running light	15.2	Watts
r_1	Primary resistance, main winding (cold)	1.07	Ohms*
r^2	Resistance starting winding (cold)	3.92	Ohms*
	Secondary resistance running $= 0.8 \times r_2'$	1.54	Ohms
r'_2	Secondary resistance locked	1.92	Ohms
X_m	Prim. reactance, main winding	3.52	Ohms
X_S	Reactance starting winding	1.67	Ohms
S_1	Primary current scale, amperes per inch		
S_2	Secondary current scale, $= S_1 \div K_p$		
S_e	Primary voltage scale, volts per inch		
K_p	$\dfrac{\textit{Permeance of Mutual Leakage Path.}}{\textit{Permeance of Mutual and Primary Leakage Paths in Parallel.}}$		
K_r	K^2_p	0.91	
R	Total resistance		
Z	Total impedance		

*Test data.

†The friction and windage loss of 17 watts includes the primary copper loss. Since the primary copper loss at the voltage at which 17 running watts were obtained is only approximately 1.5 watts, it is negligible in this case.

determined from an auxiliary diagram, Fig. 3, as follows:—Let S_1 = 3 amperes per inch; and S_e = 22 volts per inch. Then

$$LR' = \frac{P_L}{ES_1} = 5.01$$

$$OL = \frac{i_L}{S_1} = 7.83$$

$$OE = \frac{E}{S_e} = 5$$

$$ZE = \frac{i_L\, r_1}{S_e} = 1.31$$

$$OM^* = \frac{i_o}{2S_1} = 0.78$$

*The true value of OM is obtained from the main field magnetizing current i_m. For this part of the calculation i_m may be assumed to be one-half of the no-load current i_o.

From these values the main winding auxiliary diagram may be drawn as shown in Fig. 3.

AUXILIARY DIAGRAMS

Lay off LR' at right angles to a convenient base line. Then with center at L and radius equal to OL locate the point O on the base line. At O erect a perpendicular equal to OE. Then lay off ZE from E parallel to OL and draw in OZ. Now draw a line from O perpen-

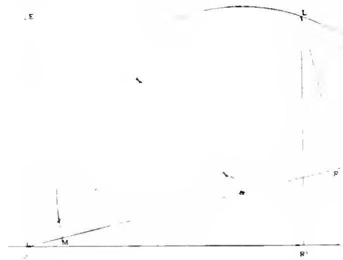

FIG. 3—MAIN WINDING AUXILIARY DIAGRAM
Diagrams are reproduced one-third size.

dicular to OZ, lay off OM on this line and draw a semicircle through points M and L with center on the perpendicular from O locating H, finally dropping a perpendicular from L to OH locating R. The auxiliary diagram is now complete, and the following values in inches are measured:—$OZ = 4.28$; $OH = 8.91$; $LH = 3.9$; $ML = 7.13$, and $OR = 7.05$. From these dimensions, the reactance, the secondary resistance, the mag-

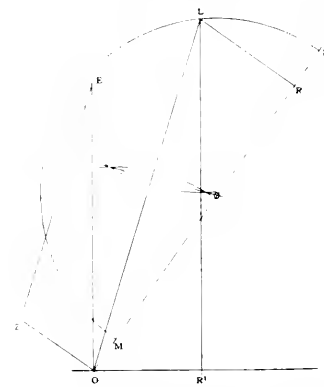

FIG. 4—STARTING WINDING AUXILIARY DIAGRAM

netizing current and the iron loss of the motor in ohms are calculated:—*

$$X_m = \frac{E \times OZ}{OH \times OE \times S_1} = 3.52$$

$$r_2' = X_m \times \frac{LH}{ML} = 1.92$$

Experience has shown that the running secondary resistance is somewhat less than the locked secondary

*Where refinements are not required the reactance, etc., may be calculated as follows:—

$$Z = \frac{E}{I_L},\ R = \frac{P_L}{i^2_L},\ X_m = \sqrt{Z^2 - R^2},\ r_2' = R - r_1$$

resistance and also that it varies with the frequency. For 60 cycle motors, the running secondary resistance referred to the primary current scale is approximately 80 percent of the locked secondary resistance referred to the primary current scale. Therefore,—

$$r_2 = 0.8 \times 1.92 = 1.54 \text{ ohms}$$

$$i_m = \frac{i_0 \times E}{2E - i_0 X_m} = 2.52 \text{ amperes}$$

$$K_r = 1 - \frac{i_m X_m}{E} = 0.91$$

$$P_s = \frac{i_0^2\, K_r\, r_2}{2} = 15.2 \text{ watts}$$

$$P_i = P_0 - (i_0^2 r_1 + P_s + P_f) = 63 \text{ watts}$$

The values thus obtained are, as previously mentioned, for the main winding only, and if starting torque is desired the reactance X_s must be determined for the starting winding in the same manner as X_m was determined for the main winding. The running values of the starting winding circuit are not available, and these

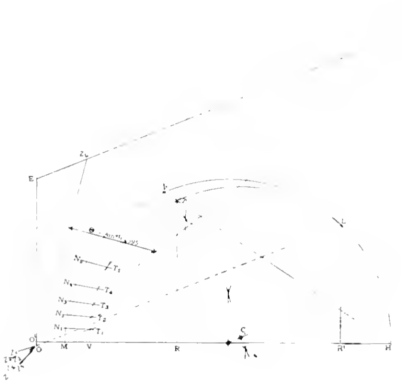

FIG. 5—PERFORMANCE DIAGRAM
$OZ = 0.73$ inch; $OZ_1 = 0.38$ inch; $OZ_2 = 0.30$ inch; $OZ_3 = 0.25$ inch; $OZ_4 = 0.22$ inch; $OZ_5 = 0.20$ inch.

values must be obtained from the main winding values by making the proper correction. The starting winding circuit values are taken from the starting winding curves of Fig. 2 and included as part of the test data in Table I.

The dimensions in inches of the starting winding auxiliary diagram calculated from test data values are:—$LR' = 6.14$; $OL = 6.43$; $OE = 5$, and $ZE = 4.29$. The scale of the starting winding auxiliary diagram is the same as the scale of the main winding auxiliary diagram. OM for the starting winding auxiliary diagram is in the same proportion to OR on the same diagram as OM is to OR on the main winding auxiliary diagram. OM is 11.1 percent of OR. Therefore, for the starting winding auxiliary diagram,—

$$OM = 0.111 \times OR = 0.111 \times 6.1 = 0.68 \text{ inches}$$

The starting winding auxiliary diagram, Fig. 4, was drawn from the above values in the same way as the main winding auxiliary diagram was constructed, and the measured values in inches are:—$OH = 6.84$; $OZ = 1.56$, and $OE = 5$. Therefore,—

$$X_s = \frac{E \times OZ}{OH \times OE \times S_1} = \frac{110 \times 1.56}{6.84 \times 5 \times 3} = 1.07 \text{ ohms}$$

PERFORMANCE DIAGRAM

The complete list of values now available for constructing the performance diagram and calculating the performance of the motor are shown in Table I.

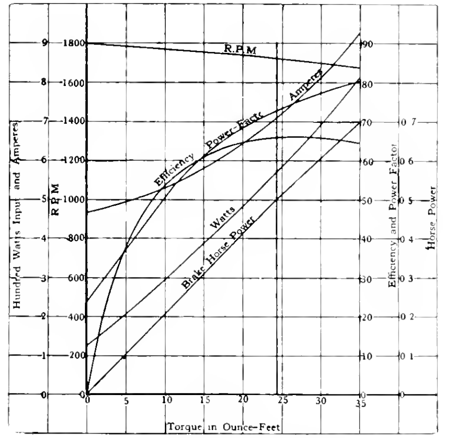

FIG. 6—CALCULATED PERFORMANCE CURVES

In calculating the performance of the motor the iron loss must be divided in two parts;—that due to the main field and that due to the cross field. As found by experimental data, the iron loss due to the main field is approximately 55 percent of the total iron loss, or in

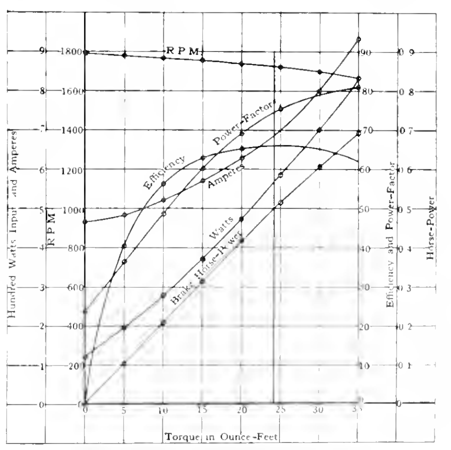

FIG. 7—BRAKE TEST CURVES
Maximum torque = 49 oz.-ft. Starting torque = 32 oz.ft.

this case 35 watts, and the cross field iron loss is approximately 45 percent of the total iron loss, or 28 watts.

The dimensions of the performance diagram, Fig. 5, are calculated as follows:—Let S_1 = four amperes per

inch; $S_2 = 4.19$ amperes per inch, and $S_e = 30$ volts per inch. Then, expressed in inches,—

$$O'H = \frac{E}{X_m \times S_1} = 7.80$$

$$O'M = \frac{i_m}{S_1} = 0.63$$

$$MH = O'H - O'M = 7.17$$

$$O'V = \frac{i_0}{S_1} = 1.17$$

$$LH = \left(\sin \tan^{-1} \frac{r_2}{X_m}\right) \times MH$$

$$= 0.400 \times 7.17 = 2.87$$

$$O'O = \frac{P_m}{E \times S_1} = 0.08$$

On a convenient base line lay off $O'M$, $O'V$ and $O'H$. Bisect MH and draw a semicircle with MH as the diameter. With H as a center and radius equal to LH locate L on the semicircle. Bisect LH and VL and where the bisecting lines intersect, point C, the center of the single-phase current locus is located. With center on C, draw a circle through V, L and H. The bisector of the arc VL cuts the single-phase current locus at point T, which is the theoretical maximum torque point. Now lay off $O'O$ perpendicular to $O'H$ to take care of the effect of iron loss in the main field. Then draw a line from H through T and locate N on the arc MLH. From O lay off OE perpendicular to $O'H$. Select a number of load points T_1, T_2, etc., on the single-phase, current locus. Measure the values OT, OT_1, OT_2, etc., and from formula,—

$$OZ = \frac{OT \times S_1 \times r_1}{S_e}$$

calculate the values of OZ, OZ_1, OZ_2, etc. Lay these values off on OT, OT_1, OT_2, etc., produced and locate the points Z, Z_1, Z_2, etc. On account of the points Z, Z_1, Z_2, etc., being so close together their exact location is not shown in Fig. 5.

The values of OT, MT, MN, TR, TH and ZE are measured for each load point selected and the running performance of the motor is calculated and tabulated in Table II. Fig. 6 was plotted from the values given in Table II. For comparison, Fig. 7 shows the performance curves of this motor obtained by brake. These curves by brake coincide almost exactly with the curves calculated by diagram. The brake test was not a laboratory brake test and consequently some variations are to be expected due to errors in observation and instrument calibration.

Starting Torque—Measure in inches $OL = 7.21$ and $LR' = 2.59$. From E (Fig. 5) draw a line parallel to OL and on this line lay off both:—

$$EZ_L = \frac{OL \times S_1 \times r_1}{S_e} = 1.18$$

$$\text{and } EZ_s = \frac{OL \times S_1 \times r_{1s}}{S_e} \times \frac{X_m}{X_s} = 0.9$$

Then draw lines from O to Z_L and Z_s and measure their lengths and the angle θ between them. The angle θ is the angle of lag of the main winding current behind the starting winding current. The sine of this angle is used in the starting torque formula and may be obtained direct by laying off on OZ_s ten units to any convenient scale and measuring the length of the line from the tenth division, which is perpendicular to OZ_L.

$$\text{Starting torque} = 225 \frac{LR_1 \times S_1 \times E}{\text{Synchronous R.P.M.}} \times \frac{OE^2}{OZ_L \times OZ_s} \sqrt{\frac{X_m}{X_s}} \times \sin\theta = 31.8 \text{ oz.—ft.}$$

TABLE II—PERFORMANCE DIAGRAM VALUES

ITEM	DESCRIPTION	LOAD POINTS					
		T_1	T_2	T_3	T_4	T_5	Max. Running T
1	OT	1.23	1.36	1.55	1.85	2.32	4.44
2	MT	0.62	0.79	1.03	1.37	1.88	3.95
3	MN	0.30	0.59	0.90	1.28	1.82	3.94
4	TH	6.62	6.62	6.60	6.56	6.46	5.66
5	TR	0.28	0.55	0.83	1.17	1.64	3.11
6	ZE	3.73	3.78	3.82	3.88	3.97	4.22
7	$\frac{OE}{ZE}$	0.982	0.97	0.959	0.945	0.923	0.868
8	$(3) \times (r_2 \div X_m)$	0.13	0.26	0.39	0.56	0.80	1.72
9	$(4)-(8)$	6.49	6.36	6.21	6.10	5.66	3.94
10	R. P. M. = $\sqrt{(9) \div (4)} \times syn$	1783	1766	1749	1722	1686	1502
11	Primary Amperes = $(1) \times (7) \times S_1$	4.83	5.27	5.95	7.00	8.57	15.42
12	Secondary Amperes = $(2) \times (7) \times S_2$	2.55	3.21	4.07	5.43	7.26	14.38
13	Secondary copper loss, cross field $= (MV \times S_2)^2 \times r_2 \times \left(\frac{R.P.M.}{syn.} \times (7)\right)^2$	6.7	6.4	6.1	5.8	5.3	3.7
14	Secondary copper loss main field = $(12)^2 \times r_2$	10.0	15.9	25.6	45.4	81.4	318.0
15	P_c	28.0	28.0	28.0	28.0	28.0	28.0
16	P_F	17.0	17.0	17.0	17.0	17.0	17.0
17	P_m	35.0	35.0	35.0	35.0	35.0	35.0
18	Primary copper loss = $(11)^2 \times r_1$	28.8	34.2	43.5	60.3	90.4	283.0
19	Secondary Input = $(5) \times (7)^2 \times S_1 \times E$	118.8	225.0	335.5	460.0	614.0	1030.0
20	Input = $(17) + (18) + (19)$	182.8	294.2	414.0	555.3	739.4	1348.0
21	Total losses = $(13) + (14) + (15) + (16) + (17) + (18)$	125.5	136.5	155.2	191.5	257.1	684.7
22	Output = $(20) - (21)$	57.3	157.7	258.8	363.8	482.3	663.3
23	Torque = $\frac{(22) \times 112.7}{R.P.M.}$ oz. ft.	3.62	10.05	16.62	23.8	32.2	49.7
24	Efficiency = $(22) \div (20)$	31.3	53.5	62.5	65.5	65.2	50.7
25	Apparent watts = $(11) \times E$	551.0	580.0	654.0	770.0	943.0	1697.0
26	Power-factor = $(20) \div (25)$	34.4	50.7	63.3	72.1	78.5	79.4
27	Horse-power = $(22) \div 746$	0.077	0.211	0.347	0.487	0.646	

Single-Phase, Two-Phase and Three-Phase Distribution

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In the early days of the electrical industry single-phase circuits were used for the distribution of alternating current. Later the polyphase system was developed, and almost simultaneously two-phase and three-phase motors and generators made their commercial appearance in 1888. At first, the preference was for two-phase current, the three-phase system being almost exclusively used for long transmission problems. Since then the three-phase system has become more popular, and the tendency is now to its exclusive use.

We will, therefore, review and study the question of conductors for each one of the above systems. We will consider each one of the above circuits as having only an ohmic resistance, which is not true, since allowance must be made for capacity, inductance and reactance, but for the sake of simplicity we will treat them as in the case of continuous current, since the impedance in each case for a short line is a factor having almost the same value.

Assume, for instance, a case where 200 kilowatts at 80 percent power-factor, alternating current is to be transmitted 10 000 ft. with a drop of potential at the receiving end of five percent, the generating voltage being in each case 2200 volts, transmission through overhead wires.

Single phase—The current in amperes will be as follows:—

$$I = \frac{200 \times 1000}{2200 \times 0.8} = 113.6 \textit{ amperes.}$$

The potential drop being five percent is therefore equal to $2200 \times 0.05 = 110$ volts. The resistance of the conductor is therefore (see Fig. 1):—

$$R = \frac{e}{I} = \frac{110}{113.6} = 0.968 \textit{ ohms.}$$

The circuit, 10 000 ft. long, requires 20 000 ft. of conductor, with a resistance per 1000 ft. of $0.968 \div 20 = 0.0484$ ohms, equivalent to a copper conductor having a cross-section of 209 310 circ.mils and weighing 635.4 lbs. per 1000 ft., or a total weight of 12 708 lbs.

Two-phase—The power in each phase being $200 \div 2 = 100$ kw, the current per phase will be:—

$$I = \frac{100 \times 1000}{2200 \times 0.8} = 56.8 \textit{ amperes,}$$

or half that of a single-phase circuit (see Fig. 2). The potential drop will be the same as found above, and therefore the conductor should have a resistance of

$$\frac{110}{56.8} = 1.936 \textit{ ohms,}$$

that is to say, twice the resistance of the single-phase circuit, because the total power is equally divided into two circuits in parallel; their individual resistance is therefore twice and their combined resistance the same as that of a single-phase circuit, as shown in Fig. 2.

Here we have two circuits in parallel, each 10 000 ft. long, each requiring 20 000 ft. of conductor, or a total of 40 000 ft., and each conductor having a resistance per 1000 ft. of $1.936 \div 20 = 0.0968$, equivalent to a copper conductor having a cross-section of 104 655 circ.mils and weighing 317.7 lbs. per 1000 ft., or a total weight for the two circuits or four conductors of 12 708 lbs.

Three-phase—The current in amperes per phase is:—

$$I = \frac{200 \times 1000}{2200 \times 1.732 \times 0.8} = 65.6 \textit{ amperes.}$$

Assuming the same potential drop as in the above cases, five percent, the watts loss in the total line equals

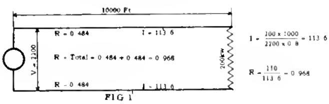

FIG 1

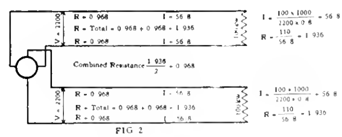

FIG 2

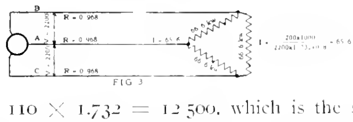

FIG 3

$65.6 \times 110 \times 1.732 = 12\,500$, which is the same as obtained in the single-phase and in the two-phase circuits for the summation of all the I^2R losses or the eI losses, the ohmic voltage drop being in phase with the current. It should be noted that in this article a five percent drop is considered as being equal to a five percent IR rather than a five percent difference between the impressed and receiver voltage. This, then, gives 4167 watts loss per line, and since this equals I^2R, $R = 4167 \div (65.6)^2 = 0.968$ ohms as the resistance of each line.

Referring to Figs. 3 and 6, we see that taking the current flowing from *A* at time of maximum instantaneous value shown in position *T* of Fig. 6, it divides at the receiving end into two equal currents 120 degrees apart, each having half the value of the current in *A* and flowing back through wires *B* and *C* to the generator. This system can be considered as made up of a circuit consisting of one phase in series with the two other phases connected in parallel.

Each branch of the circuit thus requires a conductor having a resistance of 0.968 ohms and, inasmuch as the

length is 10 000 ft., the resistance of the conductor per 1000 ft. is $0.968 \div 10 = 0.0968$, equivalent to a copper conductor having a cross-section of 104 655 circ.mils and weighing 317.7 lbs. per 1000 ft., or a total weight for the three phases of 9531 lbs., or 75 percent of the copper required for either single or two-phase circuits.

If we consider the three-phase system for each instantaneous value of current in each phase, we see, by reference to Figs. 3 and 6, that the current in each phase flows from the generator in one direction during half a period, or 180 degrees, and passes through all instantaneous values of the sine wave from zero to maximum positive and then back to zero; then repeating the same performance, but in the opposite direction,—that is, with a negative sign during the other half period, or 180 degrees, which completes the cycle.

During the first 60 degrees of rotation of each half-cycle the total current of the system flows from phases *A* and *C* to the receiver and returns in the wire of phase *B* to the generator. During the next 60 degrees it flows from the generator in phase *A* only and returns again partly in phases *B* and *C*; and during the last 60 degrees of that half-cycle it flows partly in *A* and *B*, returning through wire *C* to the generator. The current of phase *A* then reverses its polarity and repeats the same performance, which also occurs in the same order in phases *B* and *C* following the time position shown in Fig. 6.

In practice the current is expressed in terms of the mean effective value which equals $\frac{I\ \text{Max.}}{\sqrt{2}}$, and is the only value that need be considered.

It is worth while to further analyze the phenomena occurring in alternating-current circuits, especially as our acquaintance with these phenomena soon ceases after we leave the alma mater curriculum to the detriment of our clear understanding of many problems that are presented for consideration.

A readily understood representation of alternating-current phenomena is given in the form of polar co-ordinates, which combines a clear exhibition of angular position or time, direction or polarity of current, as well as value or amplitude, so that the entire performance is apparent at a glance. In polar co-ordinates the radius vector for any time position gives the instantaneous value of the phenomena. In Figs. 4, 5 and 6 are represented single, two and three-phase currents which being assumed to be of a sine wave and balanced, are indicated by circles whose diameters correspond to the relative instantaneous maximum value of each corresponding current.

A single-phase current is shown in Fig. 4, the line *OT* representing the time rotating counterclockwise around the center of rotation of the system *O*, and passing by all the current values of the phase indicated by a circle for a sine wave. The maximum value is reached when the time in its complete revolution for a cycle attains the angular positions 90° and 270°; therefore, in time position *OT* the current is at maximum positive value, or $113.6 \times \sqrt{2} \times \sin 90° = 160.6$; as the time line further rotates, the current gradually decreases in value until it reaches zero at time position *OT'*, then again raises gradually in a reverse direction of flow, or with a negative sign during the second half of the cycle.

A two-phase system is shown in Fig. 5, the phases being in 90 degrees relation. Here when the current is maximum in phase *A*, as represented by the time position *OT*, it is at minimum or zero in phase *B*. The minimum instantaneous value of the currents in both phases *A* and *B* is reached at time position *OT'*, when the current in each phase is $(56.8 \times \sqrt{2}) \times \sin. 45° = 56.8$ amperes. The current in each phase has half the value of the single-phase current in Fig. 4 for each corresponding time position in phases *A* and *B* and, as the circuit consists of two looped wires independent of each other, the total weight of the conductors is the same as for the single-phase circuit, that is, they have half the cross-section but twice the length. Inasmuch as when the current in one phase is at maximum it is at zero in the other, it is possible when the phases are not electrically interconnected to use a common return for the two phases. This reduces the number of wires from four to three, thus effecting a saving of 25 percent in the conductors. The current in the common

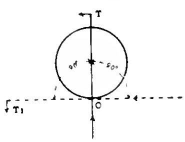

FIG. 4

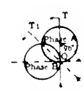

FIG. 5

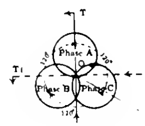

FIG. 6

Fig. 4—Single-phase current. Fig. 5—Two-phase current.
Fig. 6—Three-phase current.

return is equal to the vector sum of the two currents at 90 degrees and is the same as the maximum value in either phase, in this case 80.3 amperes

The advantage resulting from the saving in conductors in a two-phase, three-wire system is largely offset by operating inconvenience. Even with balanced load in each phase the current in the middle wire is 41 percent greater than in the outside wires. This system carries unbalanced currents and, the line drop being greater in the common return wire than in the outside ones, the phase angle symmetry of the voltage at the receiver end is affected to the detriment of the regulation of the circuit. These conditions are greatly aggravated if the system has its phases unbalanced or each phase with a different power-factor. Furthermore, the voltage across the two outside wires is equal to their vector sum, or 41 percent greater than the phase voltage, and requires additional insulation, or else they are subjected to greater stresses. Besides, special care must be taken in making connections to apparatus on account of this difference of voltage between wires.

The inconvenience resulting from a greater current density in the middle wire could be overcome by increasing its cross-section 41 percent, in which case the sav-

ing in conductors would be reduced to $341 \div 4 = 85$ percent that of a two-phase, four-wire system, the saving being only 15 instead of 25 percent.

A three-phase system is represented in the same manner on Fig. 6, each phase being 120 degrees from the others. In time position OT the current is at maximum in phase A, or $65.6 \times \sqrt{2} = 92.8$ amperes, and in phases B and C is $92.8 \times \sin. 30 = 46.4$ amperes, or half the value of that of phase A and flowing in the opposite direction. In this system, as in the two others, the time rotates around point O, the center of rotation of the system. The minimum instantaneous value of any of the phases is attained when in time position OT', where the current in phase A is zero, and $92.8 \times \sin. 60 = 80.4$ amperes in phases B and C, respectively, but in opposite directions. It is to be noted that at all instants in the three-phase system the total sum of all currents is always zero; also that potential drop follows the cycloidal function of the period, as well as the current and voltage in each branch, starting from zero, then increasing to maximum and positive, and then decreasing, passing by zero and following in the reversal order or negative to complete the cycle.

The relation of the receiving end voltage to the generator voltage is shown with polar co-ordinates in Fig. 7, for a single-phase current where both current and voltage are in phase. When, however, the current is lagging or leading the voltage, the potential drop does not follow the cycloidal amplitude of either, but causes a further phase displacement of the receiving end voltage. Where the wave is distorted and not a sine wave, the displacement reaches greater proportions and its graphical representation requires the plotting of ordinates. In three-wire, two-phase and three-phase circuits, an unbalancing of the phases also affects the shape and value of the voltage wave at the receiving end. Summarizing the results obtained in the three systems of distribution, as calculated before, gives Table I. From this table it is apparent that a three-phase system, as to cost of conductor, carrying the same amount of power over the same distance with the same line drop, is 25 percent cheaper than either single or two-phase. Assuming an existing single-phase line of the size and capacity given above, if we change this line from single to three-phase by the addition of a third wire of the same cross-section, the capacity of the three-phase line for the same drop of voltage would be increased from 200 to 400 kw, or 100 percent, with an increase in the weight of copper of only 50 percent.

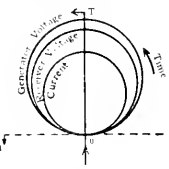

FIG. 7—RELATION BETWEEN RECEIVER VOLTAGE, GENERATOR VOLTAGE AND CURRENT

In the case of an existing two-phase line having the conditions stated above, the removal of one of the four wires and the change from two phase to three phase, would bring the capacity of the three-phase line, with the same drop of voltage, the same as that of the two-phase line, saving one of the four wires, or 25 percent of copper.

But the advantage of the three-phase, three-wire system is not limited to the economy in line conductors; it reaches further. The capital investment is also reduced, inasmuch as only three pins, three insulators and three ties are necessary at each supporting structure: three lightning arresters, three-pole switches and fuses are required instead of four-pole apparatus. These notable savings also extend to the customer service and installation, with corresponding reduction in the weight of conductors, number of insulators, pins, brackets, entrance tubes, etc., including smaller size of conduits and fittings. To the above should be added the savings in freight, haulage and labor of installation.

From the operating and maintenance point of view, the three-phase, three-wire system increases the efficiency and the safety, because decreased weight of the conductors reduces the mechanical stresses on the supporting structures, especially in cases of storms, sleet or high wind; the contingencies of mechanical and electrical failures of the insulators or insulation are reduced to three-fourths the number of those occurring in a two-phase system.

TABLE I

	Single-Phase	Two-Phase	Three-Phase
Kilowatts	200	200	200
Generated voltage	2200	2200	2200
Percent line drop	5	5	5
Potential drop	110	110	110
Receiver voltage	2111	2111	2111
Power-Factor, percent	80	80	80
Amp. per line	113.6	56.8	65.6
Resistance of each wire	0.484	0.968	0.968
Section of conductor	209,310 CM	104,655 CM	104 655 CM
Nearest commercial size	0000	0	0
Number of conductors	2	4	3
Resistance per group	0.968	0.968	
Weight of copper	12 708 lb	12 708 lb	9 531 lb.
Ratio of conductor	100	100	75

In favor of the single-phase system is the simplicity of the connections and wiring, as well as the permanence of the balance of the load. The two-phase system has the advantage of requiring only two transformers for polyphase distribution, while the three-phase system generally involves three, although such a service can be equally well maintained with only two transformers connected either open delta or T. Where three transformers are used in three-phase distribution, it is possible in case of accident to one unit to maintain the service with the other two at reduced capacity. In two-phase distribution the loss of one transformer cripples the installation entirely, an incident of serious consideration.

The foregoing reviews briefly the advantages offered by the three-phase, three-wire system of alternating current distribution. To these advantages must be added those derived from such a system which offers a greater flexibility in its operation and a greater number of polyphase connections, while permitting the use of single-phase and two-phase apparatus and motors by providing proper taps on the transformers.

Enclosed Induction Motors

O. C. Schoenfeld

IN MANY services alternating-current motors are operated in places where the atmosphere is laden with impurities, such as dust, fumes and moisture, which are injurious to the windings. Where these conditions are so severe that the windings cannot be specially treated to resist the action of the impurities it is necessary to enclose the motors so that the impurities cannot enter them.

Enclosed motors for this purpose are of several different types, which may be classed as:—

Totally enclosed motors.
Enclosed ventilated motors { Self-ventilated. / Forced ventilated.

The totally enclosed motor is one in which all openings are closed so that no air passes through the motor.

The enclosed ventilated type is completely enclosed, with the exception of an air inlet and outlet arranged for pipe attachment, as shown in Fig. 1. Clean air is then piped from an available source to the inlet of the motor, passed through the motor and exhausted into the outlet pipe, which carries it again to the clean atmosphere. It is necessary to pipe the air from the outlet into the clean atmosphere, so that when the motor is not running impure air will not enter it through the outlet. In the self-ventilated type the air is passed through the motor and piping by means of a blower mounted within the motor on the revolving member. In the forced ventilated type the air is passed through the motor and piping by means of an external blower driven either by a small motor or from a pulley on the motor shaft.

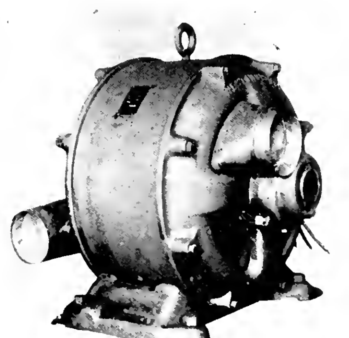

FIG. 1—ENCLOSED VENTILATED TYPE INDUCTION MOTOR
Showing air inlet and outlet.

The totally enclosed motor, as ordinarily built, is sufficiently enclosed to keep out dust, most fumes, and moisture in the form of vapor or very fine spray. Where the moisture is in the form of a heavy spray, as on the decks of ships, it is necessary to use a spray-proof motor especially built with water-tight joints. These motors are not submergible and are expensive and difficult to build.

The totally enclosed motor is the simplest to install, as there is no piping necessary, and in the smaller sizes is the most desirable type; but for continuous service the totally enclosed motor cannot be built economically above 35 to 40 horse-power. For intermittent service these limits can be increased in inverse proportion to the length of the cycle of operation. This limit in output is due to the large size of frame required to dissipate the losses in the motor.

In the open motor the heat from the losses in the winding and core is carried away partly by air that is passed through the motor by the blowers on the rotor, and partly by radiation and convection from the external surface of the motor. Since no air passes through the enclosed motor the heat must be dissipated from this

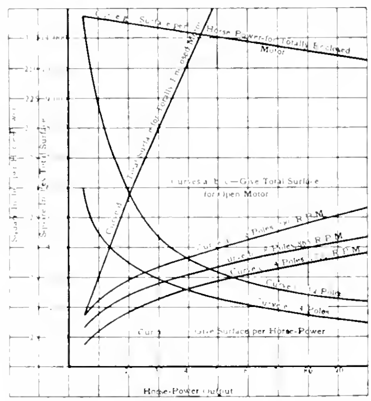

FIG. 2—RELATION BETWEEN SURFACE AND HORSE-POWER OUTPUT OF OPEN AND TOTALLY ENCLOSED INDUCTION MOTORS

type entirely by radiation and convection from the external surface of the motor, and it has been found that from 2 to 2.5 square inches of motor surface are required for each watt lost in the motor to maintain a temperature rise of 55 degrees C. for continuous service. It is then necessary to increase the size of the enclosed motor to give sufficient external surface to dissipate the losses. The comparative amount of surface of the open and enclosed motor for different horse-power outputs is shown by the curves in Fig. 2. Curves *a*, *b* and *c* show the external surface of standard open motors, for different speeds and horse-powers, while curve *d* shows the external surface required for totally enclosed motors for practically all speeds. It is seen that the curves for the open and enclosed motors diverge very rapidly as the horse-power increases, and that even at 35 horse-power the increase in the surface of the enclosed motor, and hence the size of the motor relative to that of the open motor, is very great. Also these curves indicate

that the increase in surface for the enclosed motor over that of the open becomes greater as the speed increases.

To afford a better means for determining the cause of the divergence of the above curves, curves *e*, *f* and *g* are given to show the square inches of surface per horse-power for different ratings. Curve *g* for the totally enclosed motor would be parallel to the axis except for the slight increase in efficiency as the horse-power increases. Curves *e* and *f* for the open motor fall off very rapidly as the horse-power increases, as can be accounted for by studying the following formulae:

Considering the motor as a cylinder and neglecting irregularities, the surface of the motor is expressed:—

$$\text{Surface} = 2(2DL + D^2)$$
$$\text{Horse-power output} = Hp = kd^2l$$

Where d = diameter of rotor.
D = diameter of outside of frame.
l = length of core.
L = length of motor over the end brackets.

For a given number of poles the ratio of L to l is practically a constant, and the ratio D to d is very nearly a constant and will be considered such for the present, so that,—

$$Hp = KD^2L$$
$$\text{Surface per hp} = 2K\frac{(2DL + D^2)}{D^2L} = \frac{1.57}{K}\left(\frac{2}{D}+\frac{1}{L}\right)$$

This equation shows that the surface per horse-power decreases as D increases with the square root of the horse-power, or as L increases with the horse-power. The ratio D to d was assumed a constant in developing the formula, but due to the fact that the depth of the primary slots does not increase materially with the diameter d, this ratio decreases with the horse-power, which still further decreases the surface per horse-power, as the output increases. These curves and formulae show that at the higher ratings the increase in size of the enclosed motor over that of the open motor is too great for practical consideration.

It is possible to reduce the size of the totally enclosed motor by increasing its dissipating surface by numerous projections or ribs on the frame and brackets, but the increase in the cost of development and manufacture of special parts offsets to a great extent the reduction in cost due to the smaller frame. It is seen, therefore, that the field of the totally enclosed motor is limited and that for the larger ratings the ventilated type must be used.

The ventilated type of motor, as previously defined, when supplied with the proper amount of air, affords the same conditions for taking care of the losses in the motor as is obtained in the open type, so that the same size frame can be used as for the open motor. In order to provide the proper size of piping, and in the case of the forced ventilated type, the proper blower outfit, it is necessary to know the amount of air required to maintain a certain temperature rise on the motor. The following tests results are given to afford a means of determining the quantity of air thus required. A 100 horse-power, three-phase, 60 cycle, eight-pole, 440 volt, squirrel-cage motor was arranged for ventilation, as shown in Fig. 1. The motor frame was completely enclosed with the exception of a seven-inch inlet in the lower part of one bracket, and an eight-inch outlet in the upper part of the opposite bracket. On the inlet end, the rotor carried a small distributing blower, and a baffle plate over the end of the spider to prevent the air passing directly through the spider. With this arrangement the air entering the motor at the inlet is directed by the baffle plate and the blower up through the windings on one end, over the core, down through the windings on the other end, and then exhausted through the outlet. The baffle plate in the spider was provided with a number of small openings to allow a small amount of air to pass through the rotor core.

Air was supplied to the motor by an external blower driven by a direct-current motor, which permitted speed adjustment for controlling the quantity of air. Temperature runs were taken with different quantities of air delivered, and for each quantity of air the load and losses were adjusted to give a temperature rise of approximately 40 degrees C. on the primary core (the

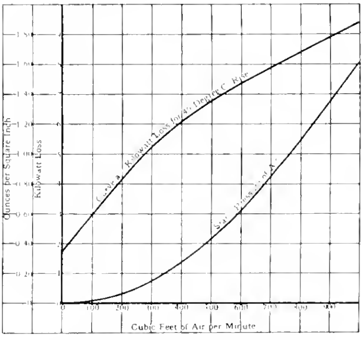

FIG. 3—RELATION BETWEEN AIR SPEED AND KILOWATT LOSS OF AN ENCLOSED VENTILATED TYPE OF MOTOR

hottest part of the motor) at the end of a continuous run. The velocity head of the air in the inlet pipe was measured by means of a Pitot tube, and from these heads and size of pipe the quantity of air per minute was calculated. The direct results of these tests are given by the curves in Fig. 3. A run was also taken with the inlet and outlet closed, giving the condition of the enclosed motor and locating the point where curve *a* crosses the axis. As an enclosed motor the losses required to produce 40 degrees C. temperature rise were 1.7 kw, while with 900 cubic feet of air per minute delivered, the losses were 8.9 kw, or 5.2 times what they were as an enclosed motor, showing the great advantage of the ventilated motor. The fact that curve *a*, Fig. 3, is not a straight line shows that the losses do not increase directly with the quantity of air delivered. The two principal factors which affect the shape of this curve are, first, the increase in the velocity of the air, and second, the change in the dissipation of heat from the external surface of the motor. In order to show the effect of these two factors, curves are plotted in Fig. 4

against the velocity of the air over the primary core. Curve *a*, Fig. 4, is plotted on the cubic feet per kilowatt basis for 40 degrees C. rise and is worked up from the losses absorbed by the air alone. The losses absorbed by the air were calculated from the rise in temperature of the air from inlet to outlet, from the relation that 0.555 watts per minute raises the temperature of one cubic foot of air (at atmosphere pressure and 25 degrees C.) one degree C. The increase in the cubic feet of air per kilowatt with increase in velocity is due to the fact that the faster the air moves over the heated surfaces the less will be the heat absorbed by each cubic foot of air. Then by subtracting the watts absorbed from the air by the total watts lost in the motor, the watts dissipated from the external surface of the motor were found, and from the watts thus calculated the watts dissipated per square inch of surface, as shown by curve *b*, were obtained. The watts thus dissipated decrease with increase in the velocity of the air, due to the fact that the air passes between the external parts

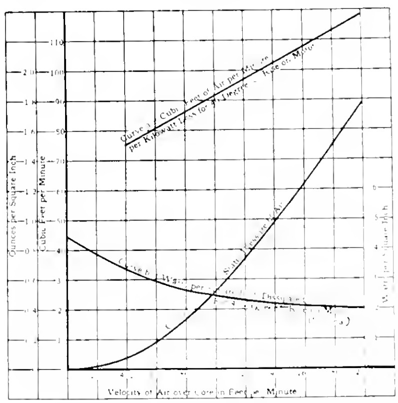

FIG. 4—RELATION BETWEEN VELOCITY OF AIR OVER PRIMARY CORE AND KILOWATT LOSS AND WATTS DISSIPATED

(frame and brackets) from which dissipation takes place, and the core and windings in which the heat is generated. The amount of heat then dissipated from the frame and brackets is received from the air within the motor and varies with the temperature of this air. As explained above, less heat is absorbed by the air per cubic foot due to increase in velocity, with the resultant lowering of the temperature of the air, and consequently a decrease in heat transmitted to the frame and brackets to be dissipated into the atmosphere. This is, of course, based on a constant temperature rise on the heat-producing parts.

From the curves *a* and *b*, Fig. 4, the amount of air required to maintain a temperature rise of 40 degrees C. for continuous service can be obtained; curve *b* giving the approximate allowance to be made for external dissipation per square inch of motor surface, and curve *a* the cubic feet of air per minute for each kilowatt of the remaining losses after the external dissipation is subtracted. These curves should be used with a factor of safety, as variation in motor construction and distribution of losses in the motor will affect the results to some extent. For temperature rises of less than 15 degrees C. above or below 40 degrees it will be sufficiently accurate to vary the values from the curves inversely with the temperature rise for the cubic feet per kilowatt and directly with temperature rise for the watts dissipated per square inch.

In order to determine the size of blower required it is necessary to know, in addition to the amount of air to be delivered, the pressure required to force the air through the motor and pipings. Curve *c*, Fig. 4, gives the pressure in ounces per square inch required to force the air through the above motor at different velocities and may be used as a guide for similar motors, but each motor must be considered on the basis of its own particular conditions that affect the pressure. For the external piping the following formula will give the drop in pressure due to the friction of the piping:—

$$h = 0.000010\frac{cLV^2}{d} \text{ for round pipes}$$

Where h = drop in pressure in ounces per square inch.
L = length of pipe in feet.
V = velocity of air in feet per minute.
d = diameter of pipe in feet.
c = co-efficient of friction which varies from 0.00008 for smooth sheet metal to 0.00010 for rough pipe.

Where there are bends in the piping they can be considered in the above formula by increasing the length of the pipe by an amount given in the following formula:—

$$L = 12.85l\left(\frac{r}{R}\right)^{0.83}$$

Where L = equivalent length in feet of straight pipe.
R = mean radius of bend in feet.
r = inside diameter of pipe.
l = length of bend measured along the center line.

Then the horse-power required to force the quantity of air through the motor and piping is found from the formula:—

$$Hp = 0.000272hQ$$

Where h = pressure in ounces per square inch.
Q = cubic feet of air per minute.

To find the horse-power required to drive the blower, the horse-power found above must be divided by the blower efficiency, which varies from 45 percent for the cone type to 65 percent for the Sirocco type. The horse-power required in any case is very small compared to the output of the large motor. For example, in the above test the watts required to drive the blower motor, when the large motor was delivering 100 horse-power, was 180 watts, or 0.24 percent of the output of the motor.

In the self-ventilated motor the amount of air is limited by the capacity of the blower that can be mounted within the motor, and in the usual arrangement a blower can be used only on one end of the rotor. The blower capacity depends upon the speed of the rotor and the space available for mounting the blower. In slow-speed motors, then, it is necessary to use larger motors in proportion to the open motors of the same rating than in the higher speed motors; and in any case

the self-ventilated type does not have as good ventilating conditions as the open motor, due to the limited space for mounting the blower. Due to the limited blower capacity the length of the piping, inlet and outlet combined, for this type is limited to approximately 25 feet with an air velocity in the inlet pipe not exceeding 1000 feet per minute.

The forced ventilated type has the advantage that an external blower can be used to suit the conditions of motor speed and length of piping, and the blower can be operated at its most efficient speed. With the external blower the cross-section of the air ducts can be reduced to give air velocities of from 2500 to 3000 feet per minute, and the quantity of air can even be increased over that of the open motor, making it possible to increase the rating, over that of the open motor, and thus to a certain extent compensate for the increased cost of installation. In buildings where a number of motors are installed, one blower can be used and the air piped to the different motors. This is particularly desirable where the source of clean air is a considerable distance from the motors. In extreme cases where clean air is not available, the forced ventilated motor offers the possibility of using air washers or air cleansers.

While the practical limit for the totally enclosed motor was placed at 35 to 40 horse-power, yet the self-ventilated type of motor, where the length of piping does not exceed 25 feet, will usually give a less expensive installation than the enclosed motor for ratings as low as 15 or 20 horse-power.

Tandem Operation of Cold-Roll Mills

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Tandem operation of cold-roll mills with individual motor drive is the latest development in the process of cold-rolling steel and requires a special form of control. These mills, as a rule, are placed from 12 to 15 feet apart and the metal is run successively through the rolls of the mills in tandem. Each successive mill is operated at a higher speed than the previous one to take up the loop in the metal between the mills caused by its elongation as it passes through the rolls. The mills are of different gear ratios, but this does not permit enough flexibility for cold-roll mills where a variation of reduction per pass is made. The additional adjustment is obtained by using two-to-one speed motors, each with a 100 point field rheostat. The rheostats of all the mills operating in tandem should be located at one place where one operator can see all the mills and regulate the loops between the rolls. This application fundamentally involves the use of a shunt motor, and the speed regulation from no load to full load during the entire speed range should be very close.

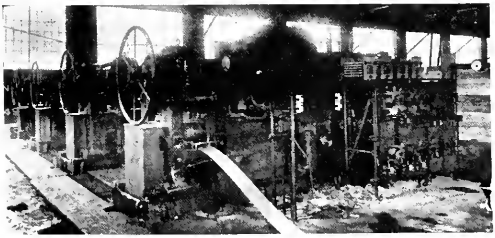

FIG. 1—FOUR 12 INCH COLD-ROLLING MILLS OPERATING IN TANDEM

The metal travels through the first mill, where a certain reduction is obtained. The speed is adjusted by means of the field rheostat shown in the foreground. An attendant takes hold of the metal as it comes out of the first mill and carries it to the second mill, where another reduction is obtained between the rolls. Similar reductions are made as the metal travels through all the mills. At the end it is wound on a steel drum, as shown in Fig. 2. Each mill is provided with one start and two stop buttons. One stop and start button is mounted beneath the field rheostat, while the other stop button is mounted on the right of the control panel. Any start button will start its respective mill, while any stop button will stop all the mills. The motors, shown mounted above the rolls, are rated at 150 horse-power, 230 volts, 400 to 800 r.p.m.

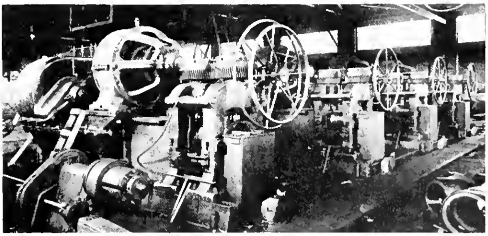

FIG. 2—FOUR MILLS OPERATING IN TANDEM

Showing metal coming out of last mill and being wound on steel drum.

The mills are started separately, but all are arranged to stop together. This feature is necessary, for otherwise the metal in the rolls and the drives themselves would be placed under undue strains. All the tripping devices of the controllers, such as overload relays and stop buttons, are wired in series. The mills can be started one after another to avoid heavy power demands.

At times it is desirable to use these mills without reference to each other, and therefore arrangements are made on all installations to change from tandem operation to single operation. This is accomplished by means of a double-throw knife switch to make the necessary changes in the control circuits. For, two, three and four mills in tandem it requires three-, five- and eight-pole double-throw knife switches. With four mills operating in tandem it is someti nes desirable not only to

operate independently, but in tandem in pairs. This arrangement is made by the use of two four-pole double-throw knife switches, instead of the eight-pole double-throw knife switch. For example:—With both switches closed in the down position the mills can be operated independently; with one of the switches closed in the up position and the other in the down position, the mills can be operated in tandem in pairs; and with both switches closed in the up position, the mills can all be operated in tandem. If, in changing to the tandem operation in pairs, the wrong switch is closed in the up position, no damage is liable, as none of the mills can be started with the change-over switches closed in that combination.

These mills are normally non-reversing, but each controller is provided with a field reverse switch to reverse the motor in an emergency, such as when a piece of metal becomes stuck in the rolls and it is desirable to back it out. As an extra precaution a third pole is added to this switch and is wired in the overload relay and stop-button circuits to stop the motor if the switch is opened while the motor is running and to make it impossible to start the motor if the switch is open. It is cheaper to add the third pole to this knife switch than to use the plunger type interlock on knife switches of this size. A 40 ampere series switch with blowout is provided to short-circuit the field resistance during starting. The coil of this relay is wired in the starting circuit and is cut out when the last resistance switch is closed. This relay has been used on installations up to 200 hp.

The controllers are supplied with a time-element device to follow behind the current limit relays. The mills normally start light and accelerate rapidly. However, there are times when the metal sticks in the rolls and acceleration under such conditions with current-limit devices would be unreliable, as the current may not drop low enough to allow the series relays to close and bring in the resistance switches. For this reason a time-element device is added to make the acceleration positive.

The first time-element used was a dashpot relay having contacts to shunt the series relay contacts when closed. The coil of this relay was energized through an interlock by the switch which actuated the series relay. The disadvantage of the dashpot relay scheme is that an additional interlock and relay is required for every accelerating switch. This scheme has been replaced by a motor-operated drum, which is simple and rugged in construction and reduces interlocks to a minimum.

In conclusion, it may be said that the use of the motor-operated drum gives this special form of control for cold-roll mills a simple, rugged, effective and cheap combination, reducing upkeep and repairs to a minimum.

Pitch Diameter of V-Grooved Pulleys

C. A. M. Weber

DETERMINATION of the working diameter or pitch diameter of a V-grooved pulley usually involves drawing it to scale or measuring the diameter over the belt with a pair of calipers and then subtracting the diameter of the belt. The former method requires time and a number of drawing instruments, while the latter requires a pulley, a belt and a pair of calipers. A simpler and more convenient method involves the use of a formula only, which is derived as follows:—

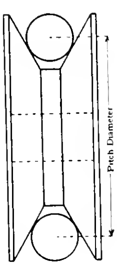

FIG. 1

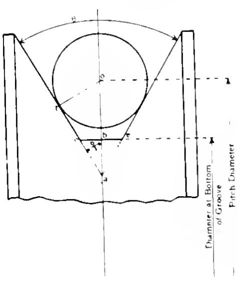

FIG. 2

Fig. 1—V-grooved pulley with belt.
Fig. 2—Same groove and belt enlarged.

In Fig. 1, which shows the most widely used form of V-grooved pulley with belt, and Fig. 2, an enlarged drawing of the same groove and belt, let,—

D = diameter at bottom of groove in inches.
d = diameter of belt in inches.
θ = angle between sides of pulley.
PD = pitch diameter in inches.

Then $PD = D + 2\,bo = D + 2\,(ao - ab)$

$$\text{But } ao = \frac{ot}{\sin\frac{\theta}{2}}$$

$$\text{And } ab = \frac{cb}{\tan\frac{\theta}{2}}$$

$$\text{Then } PD = D + 2\left(\frac{ot}{\sin\frac{\theta}{2}} - \frac{cb}{\tan\frac{\theta}{2}}\right)$$

and since $d = 2\,ot$ and $ce = 2\,cb$

$$PD = D + \frac{d}{\sin\frac{\theta}{2}} - \frac{ce}{\tan\frac{\theta}{2}}$$

When $\theta = 60$ *degrees*, $PD = D + 2d - \sqrt{3}\,ce$
When $\theta = 45$ *degrees*, $PD = D + 2.61d - 2.41ce$

Thus, for 5/16 inch diameter belt and 3/32 inch width of groove at bottom, when θ = 60 degrees, $PD = D + 0.46$ inch, and when θ = 45 degrees, $PD = D + 0.55$ inch.

Effect of Direction of Grain on Magnetic Properties of Silicon Sheet Steel

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Research Engineering Dept.,
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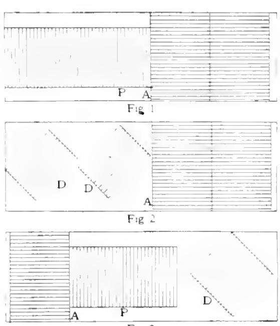
IT HAS been known for some time that if a magnetic flux is caused to pass through a sheet of steel parallel to the direction in which the sheet was rolled, the material will appear to have different hysteresis-loss and permeability characteristics than is the case if the flux passes through in some other direction, but little quantitative data have been published on this subject. During the past few years a large number of tests have been made on silicon steel with a view of determining the magnitude of this effect. Three directions of grain were investigated by the authors;—with the flux parallel to, with the flux perpendicular to, and with the flux making an angle of 45 degrees with the direction of sheet rolling.

TEST METHODS

The relation between the parallel and the perpendicular directions of grain was first investigated. Samples



FIGS. 1, 2 and 3—METHOD OF CUTTING SAMPLES FROM METAL SHEETS
A—Parallel; *P*—Perpendicular; *D*—Diagonal.

from 234 lots, representing over three million pounds of silicon steel, were tested. The steel had a nominal thickness of 0.014 in. (0.0356 cm). Four sheets were taken from each lot and sheared into strips 50 by 3 cm, as shown in Fig. 1. The parallel strips were marked *A* and the perpendicular strips *P*. A five-kilogram sample was made up from both the *A* and *P* strips for watt loss tests, and an average one-kilogram sample of each for permeability tests. Watt loss tests were made at an induction of 10 000 gausses, 60 cycles by means of a standard Epstein apparatus. Permeability tests were made at inductions of 6000, 10 000 and 16 000 gausses by means of a Burrows apparatus.* After completing tests on the samples as received, they were annealed and again tested. They were then reannealed and given a final test. The original sheets had been given one annealing at the mills.

After having completed the perpendicular grain tests samples were taken with the grain diagonal from 89 lots, representing over one million pounds of steel. Four sheets were taken from each lot and sheared into strips, as shown in Fig. 2. The parallel strips were marked *A* and diagonal *D*. The treatment and tests were the same as for the perpendicular strips.

*Described in Technical Paper 117 of the Bureau of Standards.

TEST RESULTS

The results of the tests on these samples, expressed in percent, are as given in Tables I to VI:—

TABLE I—PERCENT DECREASE IN WATT LOSS DUE TO ANNEALING FOR *A* AND *P* SAMPLES

Treatment	No. of Samples	*A*	*P*
First Anneal	234	9 3	7 5
Second Anneal	234	3 5	2 8
Total	. .	12 5	10 1

TABLE II—PERCENT DECREASE IN WATT LOSS DUE TO ANNEALING FOR *A* AND *D* SAMPLES

Treatment	No. of Samples	*A*	*D*
First Anneal	89	10.6	8 4
Second Anneal	*81	1.9	1.5
Total		12.3	9.8

*Some of the second anneal samples were omitted, as they were bent in annealing.

TABLE III—PERCENT WATT LOSS OF *P* AND *D* SAMPLES WITH RESPECT TO THE LOSS OF THE *A* SAMPLES

Treatment	*P*	*D*
As received	112 0	102.8
First Anneal	114 2	105 6
Second Anneal	114 9	107 0

TABLE IV—PERCENT INCREASE OF PERMEABILITY DUE TO ANNEALING FOR *A* AND *P* SAMPLES

Treatment	$B = 6000$		$B = 10\,000$		$B = 16\,000$	
	A	*P*	*A*	*P*	*A*	*P*
First Anneal	14 9	29 7	36 8	39 4	5 2	−1 7
Second Anneal	9 6	0 3	13 0	5 3	−2 5	2 8
Total	26 0	30 1	54 5	46 8	2 6	1.1

*All totals are based on material as received.

TABLE V—PERCENT INCREASE OF PERMEABILITY DUE TO ANNEALING FOR *A* AND *D* SAMPLES

Treatment	B = 6 000		B = 10 000		B = 16 000	
	A	*D*	*A*	*D*	*A*	*D*
First Anneal	21.6	18.5	44.5	33.0	−4.5	−7.0
Second Anneal	10.5	6.3	13.3	11.0	−5.5	−10.0
Total	34.4	25.8	63.7	47.5	−9.8	−16.3

TABLE VI—PERCENT PERMEABILITY OF *P* AND *D* SAMPLES WITH RESPECT TO THE PERMEABILITY OF THE *A* SAMPLES

Treatment	B = 6 000		B = 10 000		B = 16 000	
	P	*D*	*P*	*D*	*P*	*D*
As Received	71.0	87.8	70.4	94.6	76.2	113.2
First Anneal	80.7	85.5	71.7	87.0	72.2	110.2
Second Anneal	73.8	82.2	66.8	85.1	76.0	105.0

In order to obtain a more detailed knowledge of the effect of grain, several sheets were taken from a typical lot of silicon steel and strips cut from each sheet, as shown in Fig. 3. Epstein samples were made up from each kind of strips, and then each sample was built into the Epstein apparatus with alternate lap and butt joints. Watt loss and magnetization curves were then obtained, as shown in Figs. 4 to 7. Later hysteresis loops were taken to compare the shape of the loops for parallel grain with those for perpendicular and diagonal grain. Fig. 8 compares the loops of *A* and *P* cut from the same sheets, and Table VII shows that the hysteresis losses for the perpendicular *P* sample exceed those of the parallel *A* sample by 19 and 20 percent by ballistic and alternating-current test, respectively.

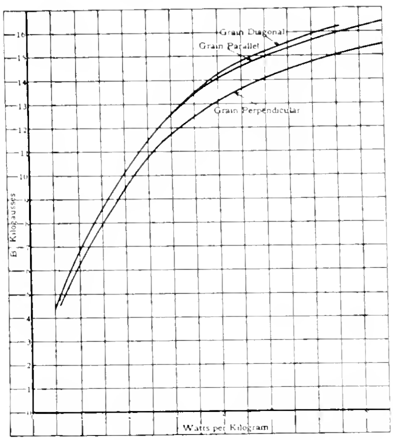


FIG. 4—EFFECT OF DIRECTION OF GRAIN ON IRON LOSS OF SILICON STEEL

Material as received.

The hysteresis loops of *A* and *D* samples cut from the same sheets of steel are compared in Fig. 6. The data in Table VIII shows the hysteresis loss of the diagonal sample to be 0.6 percent higher than the parallel sample by ballistic test, and about four percent lower by alternating-current test. It is unfortunate that the loops of Figs. 5 and 6 were taken from different heats of steel. Although the comparison with the parallel grain sample is valid in each case no comparison between the per-

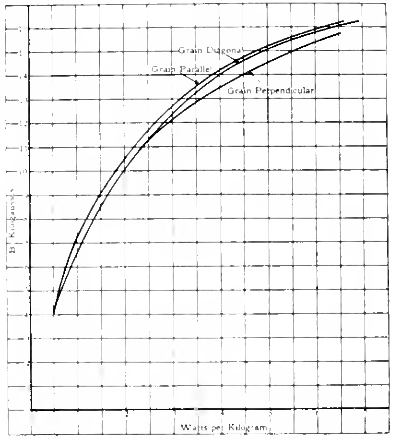


FIG. 5—EFFECT OF DIRECTION OF GRAIN ON IRON LOSS OF SILICON STEEL

Material annealed.

pendicular and diagonal samples is possible because of the difference between the parallel *A* samples in the two cases. On the average, the losses in diagonal grain samples will be found to be from two to seven percent higher than the parallel grain losses, as shown by the early tests on 89 lots of steel.

In the results shown in Tables VII and VIII the eddy-current loss was obtained by subtracting the hysteresis loss, as calculated from the hysteresis loop, from the combined loss as obtained by wattmeter. It was assumed that the eddy-current loss was the same

TABLE VII

Sample	Alternating-Current Test Watts per Kilogram				Ballistic Test Watts Per Kilogram
	Total	Eddy Currents Obs.	Eddy Currents Mean	Hysteresis	Hysteresis
A . . .	1.81	0.22	0.23	1.58	1.59
P . .	2.13	0.24	0.23	1.90	1.89

TABLE VIII

Sample	Alternating-Current Test Watts Per Kilogram				Ballistic Test Watts Per Kilogram
	Total	Eddy Currents Obs.	Eddy Currents Mean	Hysteresis	Hysteresis
A	1.87	0.27	0.23	1.64	1.60
D	1.80	0.19	0.23	1.57	1.61

no matter what the direction of grain. The eddy-current loss for the *A* and *P* or *A* and *D* samples of a lot was averaged and subtracted from the alternating loss to get the hysteresis loss from the alternating-current test.

DISCUSSION OF RESULTS

It will be seen from Tables I and II and III and IV that the *A* samples do not show quite the same per-

centage change due to annealing for each pair of tables. The tests were made six to eight months apart, and this difference is undoubtedly due to changes in material and heat treatments. The samples were annealed in large furnaces with regular charges of sheet steel and the heat cycles were subject to more or less variation.

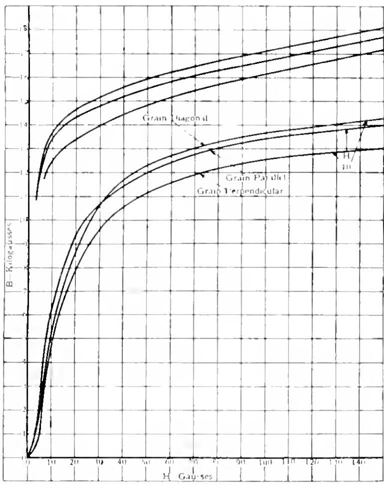


FIG. 6—EFFECT OF DIRECTION OF GRAIN ON PERMEABILITY OF SILICON STEEL
Material as received.

There is very little difference in the A and D hysteresis loops of Fig. 9, but these were obtained on samples "as received." It will be noted from Tables III and VI that at $B = 10\,000$ under these conditions the A and D samples on the average are not far different from each other.

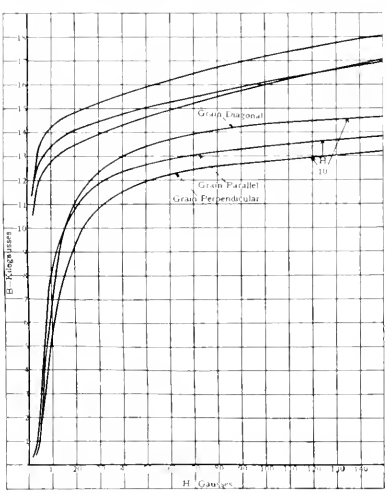


FIG. 7—EFFECT OF DIRECTION OF GRAIN ON PERMEABILITY OF SILICON STEEL
Material annealed.

From the magnetization curves of Figs. 6 and 7 it will be noted that the diagonal-grain sample has considerably higher permeability at the high inductions than the other two. This is in line with the average values given in Table VI.

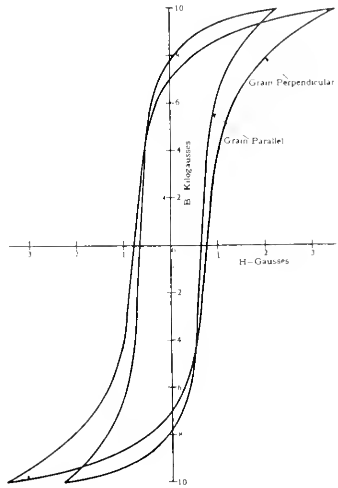


FIG. 8—EFFECT OF DIRECTION OF GRAIN ON SHAPE OF HYSTERESIS LOOP

The assumption in preparing Tables VII and VIII, that the eddy-current losses were the same independent of the direction of grain, is based on the fact that, as far as is known, no one has ever been able to find any appreciable difference in the resistance of sheet steel for different directions of grain. For this reason it seems entirely probable that the difference in losses with direction of grain is due to a change in hysteresis alone.

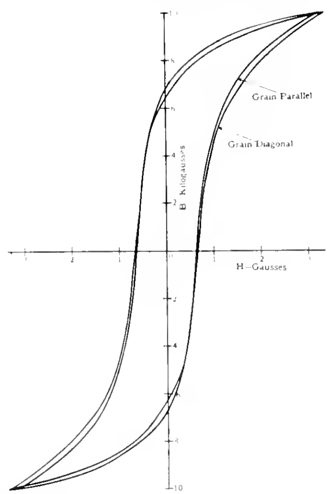


FIG. 9—EFFECT OF DIRECTION OF GRAIN ON SHAPE OF HYSTERESIS LOOP
Composite sample.

CONCLUSIONS

1—The watt loss of the perpendicular *P* and diagonal *D* samples was not so greatly improved by annealing as was that of the parallel *A* grain samples.

2—With respect to permeability, the *P* samples were improved by annealing about as much as the *A* samples, but the D samples were not so much improved by annealing as were the *A* samples.

3—The difference between the *A*, *P* and *D* samples is a function of the heat treatment, as well as the direction of rolling. This is especially evident in Table III, showing watt loss.

4—Perhaps the most interesting feature of the data presented is the fact that, while the *P* samples show a fairly uniform percentage difference in permeability from the *A* samples at the different inductions, the *D* samples are lower at 6000 and 10 000 gausses and higher at 16 000 gausses.

5—From an examination of the individual tests (the results of which obviously could not be included here) it develops that occasionally the watt loss or permeability for the diagonal grain sample may be superior to that of the parallel grain sample cut from the same sheet.

6—In transformers the grain usually runs parallel or at an angle of 45 degrees with the direction of flux. A test on a composite sample of steel cut half parallel to the grain and half perpendicular may give no indication of the quality of the steel with the grain cut at an angle of 45 degrees, and will often give a value far from the parallel grain quality. For this reason it would seem inadvisable to sample silicon steel in this way as recommended by the American Society for Testing Materials. If other than parallel grain data is required it should be obtained on a sample sheared with the grain in the same direction as it is to be used. It is usually satisfactory to make all tests with the grain parallel to the flux and then use a factor if the material is to be used under other conditions.

7—Distributing transformers, which in general are built of L plates having the grain at an angle of 45 degrees with the flux, for reasons of economy in punching, may have their iron losses satisfactorily calculated by adding five or six percent to the parallel grain test losses.

8—Whenever it is possible to avoid it, silicon sheet steel should not be used with the induction perpendicular to the direction of grain, since the magnetic properties under this condition are not as good.

Engineering Notes

Conducted by R. H. WILLARD

Aim—To connect theory and practice

Sparking on Self-Starting Converters

When a self-starting, commutating-pole converter is started it is customary to raise the direct-current brushes to avoid bad sparking. The converter is started by applying a low voltage to the armature with no field excitation. Being a polyphase winding, the armature produces a rotating magnetic field (like an induction motor primary), which reacts on the short-circuited damper bars placed in the pole faces and causes the armature to rotate. The rotating armature flux not only cuts the damper

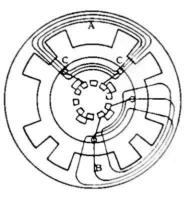


FIG. 1

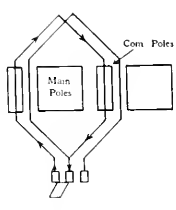


FIG. 2

bars, but also the armature conductors and generates in them a counter e.m.f. In a commutating-pole converter the coils whose commutator segments are under a brush are directly under the commutating pole. This gives a path of low reluctance for the armature flux around the path *A*, Fig. 1, so that when a pole of the rotating field passes under a commutating pole a large flux flows through path *A*. This flux cuts the conductors *C C* and induces a voltage in them. These conductors, however, are being short-circuited by the brush, so that a heavy local current flows through the coil, as shown in Fig. 2. As the armature moves, the brush breaks this current and causes a bad spark. The rotating field also cuts the conductors under the main pole, as at *B*, but as these conductors are not short-circuited no current flows, due to this generated e.m.f., which acts merely as a counter e.m.f.

This trouble is not so bad with non-commutating pole converters, as the coils undergoing commutation are between poles and the magnetic path through these coils has a very high reluctance, so that very little flux is developed.

Operation of a 50 Cycle Transformer on 25 Cycles

In a transformer the resistance and reactance drops are very small, so that the counter e.m.f. is very nearly equal to the line e.m.f. The counter e.m.f. is proportional to the rate of change of flux. In a given transformer the counter e.m.f. is proportional to the product of the flux density and frequency.

$$E_c \propto Bf \text{ or } B \propto \frac{E_c}{f}$$

If the frequency is changed without changing voltage, $B \propto \frac{1}{f}$ so that doubling the frequency halves the flux density and vice versa. Power loss in hysteresis is $P_h \propto fB^{1.6}$, or since

$$B \propto \frac{1}{f},\ P_h \propto \frac{f}{f^{1.6}} \propto \frac{1}{f^{0.6}}$$

so that hysteresis loss varies inversely as the 0.6 power of the

frequency. Eddy-current loss is $P_e \propto f^2B^2 \propto \frac{f^2}{f^2}$, so it is independent of frequency variations. If a 50 cycle transformer be run on 25 cycles, the hysteresis loss is increased $2^{0.6}$ times and the transformer will run hot at no load. This increased flux density also requires a much larger magnetizing current, even if the iron does not become saturated, and as the iron in an ordinary transformer is very liable to become saturated at the double flux required at half frequency, the operation is not at all satisfactory.

Connection of Three-Phase Shell and Core-Type Transformers

In three-phase, shell-type transformers the middle phase is always reversed on both primary and secondary sides This is on account of the flux relations in the core. Fig. 1 shows a section of a shell-type transformer without the phase reversed. Let the vector figure represent the fluxes in the three phases, their instantaneous values being represented by the projection of the vectors on the vertical line. At the instant shown, flux A is a positive maximum, B and C are half value negative. Suppose that positive direction of flux is to the right between the coils. The flux will circulate as shown by the arrows. The fluxes between A and B add, giving a flux of 1.5 times the maximum of one phase. Fig. 2 shows the vector position an instant later, when flux C is 0.866 full value positive, and flux B is 0.866 full value negative. These add between B and C, giving a flux of 1.732 through the iron. Figs. 3 and 4 show corresponding conditions with phase B reversed. In this case the iron between phases is at no time carrying more than the maximum flux of one phase. By connecting in this way a high flux density in the iron between phases is avoided. The connections are generally made by jumpers on the terminal board of the transformer.

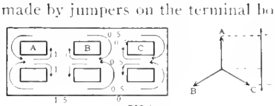


FIG 1

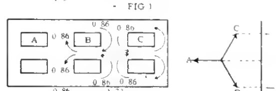


FIG 2

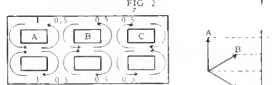


FIG 3

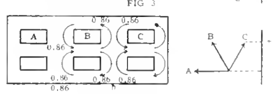


FIG 4

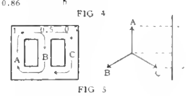


FIG 5

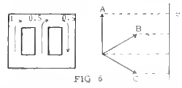


FIG 6

Care must be taken not to reverse a phase of a core-type transformer. Assume that positive flux is up in Figs. 5 and 6. It will be noticed that with phases uncrossed, Fig. 5, all the flux going up in one path comes down through the other two; while with one phase crossed, Fig. 6, more flux tends to flow up than down. Since in a three-phase circuit the algebraic sum of all the e.m.f.'s is zero at every instant, the sum of the counter e.m.f.'s must be zero, making the sum of the fluxes zero. This means that all the flux that goes in the positive direction, up, must return in the negative direction, down; if the coils are not connected so as to produce this condition, the counter e.m.f.'s of the phases will not be balanced and a heavy unbalanced current will flow.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1327—Speed of Rotary Converter—We have two 250 kw, shunt-wound, two-phase, 25 cycle, 150 volt, 375 r.p.m. rotary converters which are started by means of a small induction motor on the end of the shaft. The speed is regulated by varying the iron losses, i. e., by varying the field excitation. The machine is started with all resistance cut out of field rheostat, and speed is regulated by cutting in field resistance. It is found that when about one-third of the field resistance is cut in the machine comes up to synchronous speed, but by moving the rheostat handle beyond this point the speed suddenly diminishes until the resistance is about three-fourths cut in, when it again reaches synchronous speed. Can you explain the above? Why does the machine reach synchronous speed for two positions of the field rheostat handle.

B. L. (NEW YORK)

We assume that the converter is started and brought partly up to speed as a self-excited machine (the shunt field rheostat being all cut out) by means of the direct-connected induction motor. After connecting to the direct-current

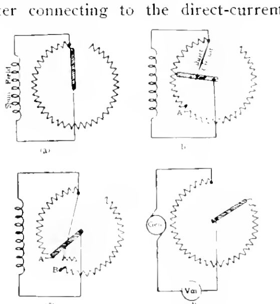


FIG. 1327 (a), (b), (c) and (d)

line the driving motor is cut off and the converter runs as a shunt motor, its speed being determined by means of the shunt field excitation. Assuming at the time of starting the connection is as per Fig. 1327(a), and as the contact arm on the rheostat is moved resistance is cut in, thereby reducing the field ampere turns and speeding up the converter armature. When some intermediate position of the contact arm of the rheostat is reached (depending upon how the successive rheostat contacts are graded as to resistance), such as one-third around as mentioned, the correct amount of resistance is inserted in the field circuit to give synchronous speed. If, as per Fig. 1327(b), a section of the rheostat has become short-circuited, then as the contact arm is rotated farther, the resistance of the rheostat would begin to be cut out. This would gradually reduce the speed of the rotary until the contact arm was over the short-circuited point *A* on the rheostat, when the same conditions would be had as in Fig. 1327(a)—all resistance cut out. By rotating the arm of the rheostat still further, resistance would again begin to be cut in until at some point (say two-thirds around) the proper resistance would be cut in to give synchronous speed. If, as mentioned in the query, the speed of the converter suddenly falls off after rotating the arm of the rheostat, beyond the point where synchronous speed is obtained, the rheostat undoubtedly has an open circuit as well as a short-circuit—one of the resistance coils become broken and fallen across as per Fig. 1327(c). This would mean that if the proper resistance were in circuit to give synchronous speed of the converter when the contact arm was at point *A*, when moving across to point *B*, all of the resistance would be at once removed, and the speed of the converter suddenly fall off. By rotating the arm of the rheostat still farther, resistance would be again cut in until at some point (such as two-thirds around) proper resistance would again be inserted to give synchronous speed. To check this, rotate the arm of the rheostat all the way around until all resistance is cut in, as in Fig. 1327(d). Impress a constant voltage upon it from some external source (generator or batteries) and insert a voltmeter. Slowly rotate the arm of the rheostat backwards (cutting out resistance) and the voltmeter will indicate the point of trouble on the rheostat.

R. H. N.

1328—Induction Generator—(a) At what speed would an induction motor rated at 1000 horse-power, no-load speed 600 r.p.m., slip estimated at 0.5 percent, have to be driven as a generator to develop 1000 horse-power? (b) What is the minimum size of synchronous generator required to furnish the excitation for the operation of the above motor, assuming a power-factor of 94 percent and slip of 0.5 percent?

R. B. G. (CALIF.)

(a) A motor as described probably would have at least 93 percent efficiency. To give an electrical output of 1000 horse-power it would have to be driven at $\frac{0.5}{0.93} = 0.537$ percent above synchronous speed. This equals $\frac{100.537}{100} \times 600 =$ 603.2 r.p.m. From this you will note that great care must be used in this connection regarding the prime mover which drives the induction motor, as to speed regulation. A prime mover which carries no load at 600 r.p.m. and full load at 603.2 r.p.m. would be regulating more closely than is usually expected. Caution is necessary on this point. From 600 r.p.m. to 600.037 r.p.m. the induction motor is acting as neither motor nor generator, but is absorbing power both electrically and mechanically in changing proportions to make up for its internal losses of 7 percent as assumed. Before attempting operation as suggested it would be well to get expert advice from operators who are using induction generators in this way. (b) This depends on the magnetizing current of the motor, and this varies widely with the number of poles. It might be as low as 15 percent of the full-load current on a high-speed motor, or as high as 40 percent on a low-speed motor. With 94 percent power-factor the total wattless component would be 34 percent of the input. As a rough approximation this would be two-thirds magnetizing component and one-third leakage. This would make the magnetizing $2/3 \times 34 = 22.6$ percent, and the synchronous exciter would have to furnish about 22.6 percent of the total current in the induction generator.

A. M. D.

1329—Magnet Operation—Referring to Fig. 1329(a), showing a magnetic circuit of laminated iron linked with coils, one of wire winding, the other a single conductor or copper sleeve. Alternating current connected to the wound coil causes the sleeve to move away from the wound coil. The sleeve in this case is pivoted at point *A* and

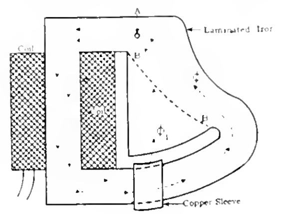


FIG. 1329(a)

operates on the same principle as a constant-current transformer. Is the current set up in sleeve by lines of force passing through sleeve ϕ_1 acted on by the lines of force cutting across sleeve, and so causing the motion of sleeve, or are the phase relations such that ϕ_1 has nothing to do with motion of sleeve? What effect would the cutting away of iron along line *BB* have on the motion of the sleeve? In this case cutting away of the iron shows no appreciable difference in the force moving the sleeve leaving "room for argument."

C. G. H. (N. J.)

(a) The motion of the coil is a result of the flux, which "leaks" between the exciting coil and sleeve. The relations between flux, current and motion are represented by the well-known hand diagram in which the index finger extending straight out represents direction of flux, the thumb extended at right angles to index finger and in the same plane as the palm of the hand represents direction of motion, and the second finger extending at right angles to the palm of the hand represents direction of

current. (b) The repulsion is proportional to the square of the ampere turns and the first power of the permeance of the leakage path between coils. The current circulating in the coil is inversely proportional to the permeance. Hence, if the voltage impressed on the exciting coil is kept constant and the repulsion at *A* inches between electrical centers of coils is *B* pounds, the current at *2A* inches will be one-half value and repulsion will be one-half *B* pounds. In other words, if a leakage path of uniform reluctance existed between the two coils the repulsion would be inversely proportional to the distance between the electrical centers of the two coils. With a complicated leakage path such as exists between the coils shown by Fig. 1329(a) it is possible that such a large percentage of the flux passes through a path which is not affected by the cutting away of iron along *BB* that there is really little change in the permeance for various positions of the copper sleeve. The natural tendency, however, would be to increase the repulsion if the iron along BB was cut away, as this would decrease the permeance and increase the repulsion. H. D. B.

1330—Water Rheostat—In using a water rheostat of iron plates suspended in the river to absorb the loads of an 11 500 volt, 627 ampere, 10 000 kw, water wheel driven generator, what should be the size and spacing of the plates? J. S. K. (CALIF.)

We have loaded machines of approximately the size you mention for test with a rheostat having steel plates submerged in the forebay. Fig. 1330 (a) and (b) will give sufficient information

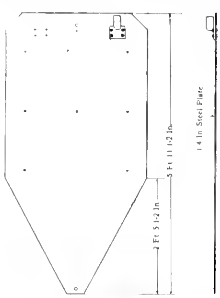


FIG. 1330(a)

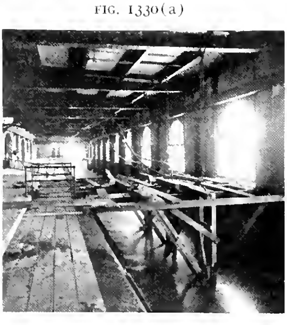


FIG. 1330(b)

to reproduce the arrangement which worked very satisfactorily. The spacing of the plates and the extent to which they may be submerged for particular loading will vary according to the character of the water in the stream and is best determined by experiment. The plates are approximately 3 ft. wide by 6 ft. long. L. E. I.

1331—Transformer Fuses—What are the proper size fuses to use to protect 100 and 200 watt potential transformers? R. B. G. (CALIF.)

Potential transformers cannot be protected by means of fuses on account of the extremely small current encountered. However, it is the practice to provide small fuses in transformer circuits for the protection of the other apparatus connected to the same circuits. K. C. R.

1332—Meter Pointer—Should the pointer of a polyphase indicating wattmeter return to the zero point at no load? If it does not, and is adjusted to do so, must the instrument be recalibrated? R. B. G. (CALIF.)

The pointer should return to the zero point at no load. Whether the instrument must be recalibrated depends upon type of meter and the method of adjustment. For instance, if the error is caused by the pointer being bent, straightening the pointer should not affect the calibration springs, whereas adjusting the springs might or might not affect the calibration, depending upon the type of meter. It is always better to recalibrate or at least check the instrument after any changes are made, as any magnetic or mechanical action violent enough to bend the pointer or otherwise throw the meter off zero might affect the calibration. C. R. R.

1333—Open Field Circuit—What would probably happen if the field circuit of a small alternating-current generator operating in parallel with a very large transmission system were opened? R. B. G. (CALIF.)

Whether the generator will continue to run in synchronism will depend on the design of the generator and, principally, on the energy load on the generator. If the magnetizing current of the generator, considered as an induction motor, is small and the load is small the chances are good that the generator would continue to operate synchronously. If the load or other conditions are less favorable it might continue to operate as an induction generator or even drop its load entirely and be put completely out of step. F. D. N.

1334—Power-Factor Correction—It is proposed to install a synchronous motor set in the main sub-station of a city electrical system in order to improve the power-factor to 95 to 100 percent and also to carry additional mechanical load in the shape of street railway load. The additional street car load, which is the mechanical load on the synchronous motor, can be taken at 250 kw. The generating station is approximately 30 miles away. Capacity of machines fully loaded is 6000 k.v.a. Line voltage is 35 000 volts, which is stepped up from 2400 volts. This load is nearly all taken up by induction motors, a comparatively small part being converted and used for street cars. One thousand kilowatts can be used for this load. There is no power-factor meter at power station, but the power-factor is being taken at 70 percent. Is that a good supposition? It is the intention to have the motor 100 percent larger than actually required at present. Please advise what size of machine to install. Will it be necessary to put a power-factor meter at the generating station? W. H. M. (NEW YORK)

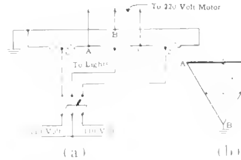
Seventy percent power-factor is a reasonable guess. Before spending any money to improve power-factor it would seem to be worth while at least to borrow a power-factor meter and find out what the power-factor really is. If there is 6000 k.v.a. load at present at 70 percent power-factor this means 4200 k.v.a. wattless component and would require a synchronous condenser of this rating to bring the power-factor up to 100 percent. Obviously, a 250 kw energy load

FIG. 1334(a)

added to this would make no appreciable increase in size of the condenser. With such a disparity between energy and wattless loads it is worth considering whether a better layout could not be obtained using a synchronous condenser, without energy load at the center of the low power-factor induction motor load and a 300 kw rotary converter at the point where the additional railway load is located. F. D. N.

1335—Transformer Connections—The primary of three single-phase transformers are connected in delta for 2300 volts. The secondaries, which have variable ratio taps, are connected in delta for running a 220 volt induction motor. Then three wires are tapped to the three middle taps on the transformer and brought to a three-pole switch which feeds the 110 volt lighting system. Also one leg of secondary is grounded, as shown in Fig. 1335(a). Please explain why the voltage for lighting circuit is not more than 110 volts. Does grounding have any effect? Would not a Y connection with common wire grounded be a better scheme? T. F. P. (NEW YORK)

This connection is correct for getting 110 volts for lighting, as will be seen by reference to the vector diagram, Fig. 1335(b). *AC*, *CB* and *BA* represent the 220 volt three-phase circuit. *X*, *Y* and *Z* represent the middle taps, and it is evident that $XY = 1/2\ BC$, $YZ = 1/2\ AB$ and $XZ = 1/2\ AC$. Since the lighting circuits are taken off *XY* and *XZ*,



(a) (b)
FIG. 1335 (a) and (b)

the voltage will be 110. The ground connection has no effect on the voltage of the lighting circuit. If the secondary windings are Y connected the voltage will be wrong for the motor, although 110 volts for lights could be secured between the grounded neutral and the middle taps. W. M. M.

1336 — Transformer Temperature — Given an 800 k.v.a., 2200/60 volt transformer with a thermometer in the shell. What is the relation between the temperature as read and the actual temperature in the interior of coils, approximately? Where can I find information in detail? Are embedded-in-coils types of pyrometers used now and are they successful? Can they be installed on a transformer now in operation without them? If so, what type is best and how installed? V. C. D. (NEW YORK)

The difference between the actual temperature of the winding and the indication of the thermometer in the shell depends upon the design and the load. With a well-ventilated winding the difference should not exceed about 20 degrees C. at full load. As the load increases this difference will increase. Thermo-couples can be placed in fairly close contact with a low-voltage winding during manufacture and will give a reasonably accurate indication of the actual temperature of the winding at that point. Thermo-couples should not be used with high-voltage windings because of danger of weakening the windings and danger of injury to attendants. Thermo-couples cannot be inserted satisfactorily in transformers after they have been built. In this case probably the best thing to do is to use a thermometer of the Bristol type and insert a bulb through an opening near the middle of the cover, letting it down until it comes as close to the windings as is safe. The bulb is then in the hot oil as it comes from the ventilating ducts. This may show a temperature 10 degrees C. in excess of the thermometer in the shell, at full load. W. M. M.

1337—Equalizer Rings—Kindly let me know the possible number of equalizer rings and connections of a lap-wound, direct-current armature for four poles, six, eight, ten, etc., and how are they spaced around the armature and commutator for a given number of coils and bars? C. A. K. (NEW YORK)

The greatest possible number of equalizer rings equals the number of commutator bars divided by the number of pairs of poles. To save mechanical space and cost it is the usual practice to put one ring connection every second or third slot, thus making the number of equalizer rings equal to one-half or one-third the number of slots divided by the number of pairs of poles. The connections to the commutator bar are usually spaced equally around the commutator. C. O. S.

1338 — Internal Resistance Motor — Please explain why an internal resistance type induction motor doesn't furnish starting torque with resistance brushes short-circuited in starting. C. E. H. (NEVADA)

It is because the secondary resistance is too low. See any good textbook for the formula for starting torque and note the effect of the secondary resistance. A. M. D.

1339 — Motor Power-Factor — What power-factor is usually obtained from squirrel-cage motors, also slip-ring motors, during starting period, when starting idle or with normal load? M. O. S. (ILL.)

The power-factor at starting is not affected by the amount of load against which the motor is starting. It averages from 40 to 55 percent. As the motor comes up to speed this figure changes, decreasing if the motor is unloaded, or increasing if the motor is loaded beyond a certain amount. The power-factor when the motor is up to full speed may be as low as 15 percent, or even less if the motor is unloaded, and depends entirely on the load carried if it is loaded. The amount of current taken by the motor at the instant of starting is also independent of the load, but the duration of the starting peak is affected by the load in that the motor comes up to speed more slowly when loaded. The initial kick of current, however, is the same at no load as if starting against full load. As these motors start very quickly when unloaded, a sluggish ammeter might not show this, but it would be found to be always true if checked with an oscillograph. A. M. D.

1340—Lamp Ground Detector—Will you please explain the action of ground detector shown in Fig. 1340(a). When switch is in receptacles *1—4* and plug makes contact between *T* and *L* there is no light; with switch across *3—4* and plug in the same position the lamp lights at full voltage; with the switch across *2—4* the same results, lamp burning at full voltage. Thus far I understand. When plug is withdrawn until contact is made between *T* and *G* lamp burns dimly when switch is between *1—4*, *3—4*, *2—4*. Does this indicate a ground? I have tested for grounds, but so far have been unable to locate any. Give a good method of testing for grounds on an alternating-current installation. This detector is on a modern station with a remote controlled switchboard. D. G. (MASS.)

With the type of ground detector described and shown on the diagram, a partial ground on a line is detached by different lamp brilliancies for the three

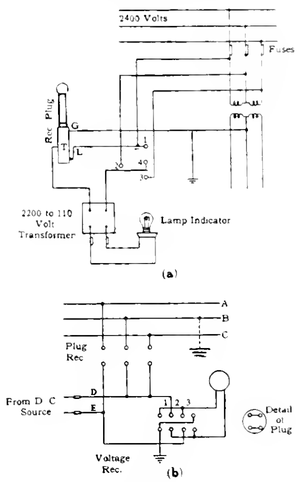


FIG. 1340 (a) and (b)

positions of the plug receptacle. The lamp will burn dimly for the line partially grounded, and somewhat brighter for the other two lines. If the line is well grounded, the lamp will not light up for the grounded line and will burn at full brilliancy for the other two lines. The dim burning of the lamp when the transformer is connected from a line to ground does not necessarily indicate that the line is grounded. The current through the lamp, even with ungrounded lines, is due to the presence of return circuits to the other two lines through the capacity of the lines to ground. If the electrostatic capacities of the three lines to ground are equal, the lamp will burn equally bright for all three lines. If the capacity is low enough, the lamp will not light up at all. As this condenser effect is present only with alternating current, the use of direct current in testing for grounds would not give indications which might be misinterpreted. Any method of testing which uses an external voltage source requires extreme precaution to prevent the possibility of testing with live lines. Electrostatic detectors or transformer and lamp detectors which are connected to the live alternating-current lines are, therefore, to be preferred. In a generating station where direct current is available from exciters and where the alternating-current system can be completely isolated, the exciter bus voltmeter may be used in testing for grounds, as indicated in Fig. 1340(b). With voltage plug in position *2*, the normal voltage impressed on the two line wires is indicated on the voltmeter, while positions *1* and *3* connect the voltmeter between lines *D* and *E*, respectively, and ground. There will be no appreciable indications on the voltmeter with clear lines. There will also be no appreciable indication for position *1* if line *B* is partially grounded, but when the voltmeter is plugged from line *E* to ground there will be a voltage indication which is inversely proportional to the amount of resistance in the ground on line *B*. If line *B* is well grounded, full voltage will be indicated for position *3* for line *E* to ground. M. C.

1341 — D.C. Motor on A.C. — What would be the results of applying 110 volts, 60 cycle, single-phase current to a one horse-power, direct-current, 110 volt series motor? Would it be self-starting and would a regulating rheostat be effective in controlling the speed? J. MC F. (CONN.)

As a rule, a series motor designed for operation on direct current will not give satisfactory service on alternating current on account of the more severe commutating conditions when alternating current is used. A motor of the size mentioned is pretty sure to give trouble on 60 cycles. If the motor is to be used for light or intermittent service and the field poles and yoke are made up from laminations instead of solid castings it might be possible to obtain fair results from the motor in question, but the following characteristics are to be expected:—1—The speed on 60 cycles will be much lower than on direct current, and consequently the capacity of the motor will be decreased. 2—The commutation will be poor, but can be bettered by undercutting the commutator mica and using a fairly hard abrasive grade of brush. 3—For a given current the heating will be considerably greater than on direct current, due to the iron loss in the field poles and yoke. This is about as complete an answer as can be given to a general question like this.

We would suggest that if the writer is interested he should experiment along the lines indicated. If the poles and yoke are made from laminations the motor should develop a considerable starting torque and a regulating rheostat will naturally be effective in altering the speed. G. H. G.

1342 — Which transformers of the delta-delta bank shown below correspond to the letters indicating the respective leads? R. B. G. (CALIF.)

It is evident that with a delta connected bank each letter marking on a line can identify that lead only. The

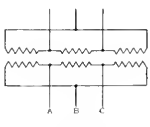


FIG. 1342(a)

transformers, in this case, could be identified by using two letters, as *AB*, *AC*, *BC*. W. M. M.

1343—**Booster Transformers**—Kindly give a schematic diagram of the booster transformers employed on the Philadelphia-Paoli electrification of the Pennsylvania Railroad, as per description in the JOURNAL, December, 1915, p. 538, and also the diagram of connections of the booster transformers in the line. J. G. K. (MICH.)

The booster track transformer is essentially a one-to-one ratio series transformer, one winding of which is connected in series with the trolleys and the other in series with the tracks. Its function is to keep the current in the tracks equal to that in the trolleys, so

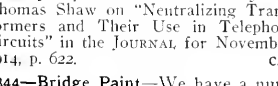


FIG. 1343(a)

that current is prevented from straying into the earth and thereby causing disturbances in neighboring telephone or telegraph systems. See article by Mr. Thomas Shaw on "Neutralizing Transformers and Their Use in Telephone Circuits" in the JOURNAL for November, 1914, p. 622. C. F.

1344—**Bridge Paint**—We have a number of bridges for signals and for supporting catenary on our road, the road having a combined electric and steam service. The bridges are becoming badly corroded, and I would like to have the name of an approved brand of paint for this work. B. T. M. (IOWA)

We recommend for any fabricated steel used for structural work, subject to the weather—first, a coat of red lead mixed in a proportion of 22 pounds to one gallon of linseed oil; if a second coat is desired, a graphite paint. This may also be applied to steel work which has already been subject to corrosion if the oxide is practically all removed before application of the paint. Red lead will absorb a certain amount of ferric oxide, but will not take care of any considerable amount. The graphite paint will not protect steel work if applied to material which has already been subjected to rust, but forms an excellent outer coating for the protection of the red lead. The latter will not hold up well under the action of rain and sunlight. It is important when applying these paints for protective purposes that the temperature should be considerably above the freezing point of water and in a dry season. J. E. S.

1345—**Tesla Oscillator**—Please give data and design particulars of a six-inch Tesla oscillator which seems to operate without the necessity of a step-up transformer from 110 volt mains, or a rotary spark gap. I am informed that such an arrangement was described by S. P. Thompson before the Physical Society in London in the year 1899 or 1900, but it does not seem to have been very much used outside the laboratory. The particulars at hand are as follows:—An electromagnet (with considerable self-induction), a condenser (3 or 4 microfarads capacity), an air core transformer (primary six-inch sheet copper, secondary a few turns of large wire). W. M. (ONT.)

We are not acquainted with any books that give design data for this scheme of producing high-frequency oscillations. The scheme is shown diagramatically by Fig. 1345(a), where *L* is an inductance, *C* an electrostatic condenser, *G* an adjustable spark gap and *T* is an air-core transformer. *L* and *C* should have such values that they will produce a resonance circuit at the frequency of the 110 volt supply. Their values can be determined from the well-known relation:—

$$\text{Resonance frequency} = \frac{1}{2\pi\sqrt{LC}}$$

$$\text{or } L = \frac{1}{4\pi^2 f^2 C}$$

Where f is the frequency, in cycles per second, of the 110 volt supply, L is inductance in henrys and C is capacitance in farads. By assigning a value to either C or L, the other can be calculated. It is necessary to have L and C very exact in value. If it is not practicable to build the inductance and condenser to give exact values, one or the other should be made adjustable. The air-core transformer should consist of two concentric cylindrical coils, the inner coil constituting the high-voltage or secondary winding, the outer coil constituting the low-voltage or primary winding. The distance between turns and the two coils should be sufficient to prevent an insulation failure at the voltage at which the outfit is to operate. The voltage of the high tension is con-

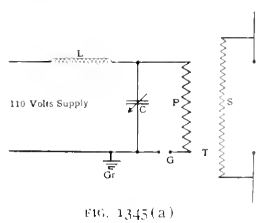


FIG. 1345(a)

trolled by adjusting the spark gap *G*. The wider the gap the higher will be the secondary voltage. The ohmic resistance of *L* should be low, since the lower this resistance is the higher will be the maximum obtainable voltage in the secondary of the air-core transformer. The operation of this outfit is as follows:—110 volts is impressed across *L* and *C* in series, and since the circuit is in resonance at the supply frequency a large current will flow. This current flowing through *L* and *C* will produce a high voltage across *L* in one direction and across *C* in the opposite direction. The voltage across *C* is also across the spark gap *G*, and since the voltage across *C* gradually increases with successive cycles of the supply current a value will be reached where a spark will occur across *G*, thus completing the circuit, including the condenser and the primary of the air-core transformer. Condenser *C* will then discharge through the primary of the transformer and high-frequency oscillations will be set up in the local circuit, and consequently high voltage will be induced in the secondary of the air-core transformer. When the condenser discharges its voltage will no longer be equal and opposite to that of the inductance, and consequently the voltage that was developed in L will be thrown on the supply lines. This may be several thousand volts. It is doubtful whether it is permissible to throw such high-voltage surges on a 110 volt supply circuit. The object of the ground at *Gr.* is to protect the operator against these high-voltage surges when operating the spark gap *G*. J. F. P.

1346 — **Trolley Wheel** — (a) What is the life of a trolley wheel? (b) What is the cause of its wearing out; is it the friction of the wheel on the wire or on its axle, or other causes? (c) What is the cause of the brilliant flashes of the trolley wheel when there is snow or ice on the wire? (d) Does it do any damage to the wheel or wire? (e) Would a trolley wheel that would not have to be renewed so often be in demand? H. A. G. (W. VA.)

(a) That depends on high-speed or low-speed service, pressure against the trolley wire, and the care and inspection of the trolley wheel. On 600 volt operation, with a maximum speed of 60 miles per hour, it will be about 4000 miles. At a speed of only 40 miles per hour, the life will be increased to about 6000 miles. For high-speed interurban operation the average is considerably less. In city service, with low speed and regular inspection of wheels, an average of 16 000 miles has been obtained. (b) Friction of the wheel on the wire. (c) The trolley wheel during its travel on the trolley wire will occasionally receive a blow from the suspension supporting the trolley wire, and with the crystallization of snow or ice on the trolley wire this will give you the brilliant flashes. (d) Yes, it increases the wear in time (e) Yes. N. A. W.

1347—**Flashing in Induction Motor Spider**—What conditions will cause a flash in the spider of a 75 horse-power, 580 r.p.m., wound-secondary induction motor with external resistance for starting. The motors are direct connected to wet pans. Stator volts 220, amperes 102, three-phase, 60 cycle, wound rotor, 305 volts, 122 amperes. The flash has occurred three times in one motor and twice in the other (four months) after motors have been running several hours. They do not blow fuses or trip oil switches. Have had one machine down and cannot find any indication of damage to core, coils or leads. F. L. S. (ILL.)

It is difficult to say from this statement what was the exact cause of the flash. Such flashes occur from several reasons, among which might be mentioned the following:—(1) Static electricity from neighboring belts or similar sources of such phenomena. (2) A loose or floating connection in some one coil that occasionally breaks the circuit and makes it again. (3) A bare spot on two adjacent conductors which should be insulated from each other, but which occasionally jar together and then separate again. This may happen between conductors side by side in the coil or it may happen at the ends of the coils outside the iron core between the top and bottom layer of the coils where the V-shaped ends cross one another. (4) The neutral or Y point on a three-phase star winding is sometimes grounded to the spider by means of a small wire. Such ground connections might become loosened and cause an occasional spark. (5) The spark might actually occur on the collector ring, but be reflected in some way so as to appear to come from the spider. The spark will probably disappear or else become more frequent, and in the latter case it can be more readily located by the local burning and its cause analyzed. A. M. D.

1348—Arc Welding Brass—Will you kindly advise whether it is possible and feasible to arc weld brass? With the metal electrode process can welding be done with a brass electrode so as to deposit brass instead of iron, as in the Slavianoff method? Is it possible to weld to brass in this manner? Is it possible to weld to iron? What flux or fluxes are best? Is the Benardos process applicable to brass? The work I have in mind is the filling in of defects in brass parts. G. F. (ILL.)

It is possible to arc weld brass by either the Benardos or the Slavianoff process, but the work is by no means commercial in character and is in a very large measure dependent upon the skill of the operator. In the Slavianoff process the welding of brass may be done either with an iron or a brass electrode, and brass may be welded to iron. All fluxes are more or less faulty, ordinary borax being perhaps as good as any. If work of this character is to be attempted (it is generally much cheaper to make the replacement or repair in some other manner) the operators should be equipped with good respirators, in addition to the usual protective hoods worn. C. B. A.

1349—Rating of Synchronous Condenser—Please explain why a three-phase generator rated at 160 kw, unity power-factor when used as a synchronous condenser at zero power-factor leading is rated at only 120 k.v.a. Also what approximately would its k.v.a. rating be and why, if when used as a synchronous motor, it is rated 200 horse-power unity power factor; 145 horse-power at 80 percent power-factor, and 125 horse-power at 70 percent power-factor. F. R. P. (OHIO)

The reason for reducing the rating of the generator, when operating as a synchronous condenser, at zero power-factor, leading, is because the field current is, assuming average design proportions, approximately 60 percent greater at 100 k.v.a. zero power-factor than at 160 k.v.a. unity power-factor. The rating of the machine as a condenser is, therefore, reduced so that the field will not overheat. The increase in field current, mentioned above, is the result of the change in the demagnetizing effect of the armature current. At zero power-factor, leading, all the armature ampere-turns are demagnetizing, while at unity power-factor only a small part are demagnetizing. The k.v.a. ratings, corresponding to the motor ratings, are 160 k.v.a. at unity power-factor, 150 k.v.a. at 80 percent power-factor, and 147 k.v.a. at 70 percent power-factor. These ratings are limited by the armature demagnetizing ampere-turns, as in the case of the zero power-factor inductive rating. The k.v.a. rating of a motor corresponding to a given horse-power is equal to

$$\frac{0.746 \times \textit{Horse-power}}{\textit{Power-factor} \times \textit{Efficiency}}.$$

L. A. B.

1350—Commutating Poles—What percent of weight is saved by designing the average 1000 kw generator with, instead of without, commutating poles? R. B. G. (CALIF.)

The weight saved by using commutating poles would depend on the speed. If the type of drive allows considerable choice in this regard, the commutating-pole machine could be built for a speed much above the speed to which commutation would limit the 1000 kw non-commutating-pole generator. The reduction in weight due to the use of commutating poles would, therefore, be large. On the other hand, if the type of drive limits the speed to a low value, the saving might be small, for other factors than commutation would then limit the output of either kind of machine. F. L. M.

1351—A.C. Solenoids—Should electrical steel sheet or transformer iron be used in building alternating-current solenoids? R. K. (CANADA)

Transformer iron is usually the best on account of its low iron loss. In special cases other iron is used. H. D. J.

1352—Exciter Operation—Two 100 kw, 125 volt, 580 r.p.m. exciters are arranged for parallel operation, but are infrequently paralleled. On one occasion the two machines were paralleled at about 70 volts, and in a very few seconds the bus-bar voltage had dropped practically to zero. The exciter which had been paralleled was disconnected, and the bus-bar voltage returned to the normal value. Later both exciters were tested and found O.K. Both units are provided with commutating poles, and it was found that the brushes on one of the exciters were about one-eighth inch from the proper position, as indicated by mark made at the factory. Could the fact that the exciters failed to operate in parallel be attributed to the defective brush setting, or to the low voltage? R. B. G. (CALIF.)

It is not likely that the slight discrepancy of brush positions will account for the loss of voltage. We are inclined to believe that the loss of voltage may be due to neglect of connecting the equalizer when paralleling. When two isolated compound-wound, direct-current machines are paralleled without the use of equalizer connections, the terminal voltage may drop nearly to zero. Assume that the two machines are paralleled at no load, and the voltage of No. 1 machine is slightly higher than that of No. 2 at the instant of paralleling. Because of its higher voltage, the No. 1 machine will force a motor current through No. 2. This current will flow through the series field of No. 1 machine in such a direction as to increase its voltage, and conversely will flow through the series on No. 2 machine in such a direction as to decrease its voltage. Obviously, such a current only increases the initial difference of voltage, and the result is that a very large current (depending upon the relative strength of shunt and series fields) flows between machines, and the terminal voltage drops to almost zero. The use of an equalizer connection will remedy this trouble. F. T. H.

1353—Growler—In the early days of alternating-current power generation was a device called a "growler" used instead of a synchroscope? R. B. G. (CALIF.)

Such a device was developed in the early days, although it was never used extensively. It consisted of a metal diaphragm which vibrated after the fashion of a diaphragm in a telephone receiver, being caused to vibrate by a differential magnet, one of the coils of which was connected across the bus-bars and the other across the incoming machine in the manner of the differential voltmeters which were also used in place of synchroscopes at the same time. The vibration of the diaphragm was proportional to the difference between any phase angles between the incoming machine and the bus-bars, the noise being loudest when the machines were entirely out of phase and being silent when the machines were exactly in phase. This apparatus had the same disadvantages that synchronizing with lights does, in that the exact instant of synchronism was not very clearly defined and also it did not indicate whether the incoming machine was fast or slow. Hence, it was entirely superseded by the improved forms of synchronizing devices. P. M. L.

1354—Bare vs. Insulated Wire—On a 6600 volt circuit, three-phase, with three No. 6 copper wires on 30 feet poles along a railroad right-of-way, would the slight saving in cost justify the use of bare copper wire? Length of circuit, two miles. What are the advantages of the weather-proof insulation for this voltage and size of wire? E. B. R. (IND.)

It would be preferable in any case to use bare conductors for the above conditions rather than the weather-proof insulation that is proposed. Weather-proof insulation would probably last only a year or two at the outside, and at the end of that time it would be in such condition that it would not be a true insulating covering. In this condition it would obviously be more of a menace than protection to life, since it would give an air of false security and so lead to possible results which a bare wire would not lead to. Therefore, it would be better to do away with all insulation from wires of this character when strung overhead as proposed. P. M. L.

FINANCIAL SECTION

SOME DEVELOPMENTS OF THE YEAR 1916

Those who followed the advice given in these columns the first of the year to purchase the stocks or bonds of electric light and power and electric railway companies have profited largely by their purchases. There has been a steady and consistent advance in the market price of these securities, they having steadily bettered their position from both a financial and an earning viewpoint. The large gains in earnings shown by these corporations have enabled them to do much needed financing, the result of which has been seen in the many new long-time bond issues which they have been able to market. Up to a year ago these companies were doing almost all their financing by short-time notes and, as a result, their interest and discount charges were large. Since the opening of the current year almost all these short-time issues have been funded by the sale of long-term securities, and it is now almost impossible for the investor to buy short-time utility notes. Those notes which are yet outstanding have advanced to high prices, and practically none of the companies has issued any new short-time securities since the first of the year. The market position of public utility bonds has been growing steadily better, and there have been advances in the lower-priced issues of from 5 to 20 points since January 1. While the improved financial condition of some of the companies have been responsible for a part of the advance, by far the larger part of the gain in price has been due to the improved earning power shown by these companies. Where a year ago companies were earning their fixed charges but one and a half or one and three-quarter times, these same companies are now showing their fixed charges earned from two and a half to three times, and this rate of increase in margin of safety has been steadily maintained month by month, the increased revenues giving every indication of permanency. It is not saying too much to say that within the last year the market position of public utility bonds has improved 50 percent; not in price alone, but also in gain in investment demand. Investors who never before had bought bonds other than listed railroad and industrial issues or municipals have now turned to the public utility securities and are finding in them what they consider the best investments of the present time. Issues of from $10 000 000 to $18 000 000 of utility bonds taken by large investment houses in the last six months have been entirely disposed of in from two to five days, and the demand for them has not been supplied. This increased investment demand has enabled many of the utility companies, which have been laboring under the handicap of having small and inadequate bond issues, to finance their expanding business by new issues to an amount not only to care for their increased capital demands, but at the same time to retire the old issues and consolidate their funded debts under one mortgage.

Statistics from the office of the controller of the currency show that the banks of the country, national, state and trust companies, have been steadily enlarging their holdings of public utility bonds, and investment houses say that they have been unable to obtain the amounts of good public utility bonds required to meet the demands of their customers. The man who bought public utility bonds at the opening of 1916 has not only had a good investment yielding a high rate of income, but today finds his holdings materially more valuable from a market viewpoint than when he purchased them. Public utility bonds are still selling on a most attractive income basis, but authorities on investments expect that this steady and sustained advance will continue in their prices until they reach a substantially lower income yield than that on which they are now selling. For this reason we repeat our advice to our readers to make their investments in bonds of well-managed and well-financed electric light, power and railway companies. By doing so they will not only secure what we believe will be found to be the maximum of safety of principal and interest, but at the same time they will find that their holdings will be steadily increasing in market prices. To a more marked degree the same has been true in public utility preferred and common stocks as in public utility bonds. The average advance in these stocks has been much larger than that in the bonds, and the market for all the better known issues has widened almost immeasurably. Securities houses which up to this year had never concerned themselves with public utility securities have, in the last six months, added departments to their business dealing in these securities, and they have found that this part of their business has been steadily growing larger.

The preferred and common stocks of Cities Service Company have been the features of the utilities market, but, while the earnings of the electric light and power and street railway subsidiaries of this company have shown large gains, its large increase in market value must be attributed to the discovery of the new and important oil fields in Butler County, Kansas, owned by Empire Gas & Fuel Company, a subsidiary. By reason of the large increase in assets and earnings of Cities Service Company, due to the development of these oil fields, the common stock, which was selling at 100 the first of the year, has advanced to 350, and the end of this advance does not seem to be in sight as yet. Cities Service preferred stock has advanced from 74 to 89, but this has largely been on the actual improved investment value as shown by the earnings of the strictly utility properties. The dividend on this stock is now being earned more than four times and, in addition, its equity in the properties of the company over and above the par value of the preferred, as shown by the market value of the common stock, is more than $64 000 000, or almost twice the par value of the entire amount of preferred stock outstanding. Reports from the strictly utility properties of Cities Service Company indicate that for the current year the preferred dividend requirements will be earned more than two and a half times by the utility properties alone without considering the revenues from the oil properties and that, after providing for the preferred dividends, there will be close to the equivalent of 20 percent a year remaining for the common stock. With the inclusion of the oil earnings, the preferred dividend will be earned more than four times, and more than 30 percent will be shown on the common stock in 1916.

Northern States Power Company of Delaware common stock has advanced from 46 to above 90, and an initial dividend of 1.5 percent has been declared on the stock. As stated some time ago would be the case, the funded debts of this company and its subsidiaries have been consolidated under a new mortgage, all short-time obligations and floating debts have been liquidated and the corporate organization of the several companies consolidated. The preferred stock has advanced to above 97.

Republic Railway & Light common stock has advanced from 22 to 39, and there are reports that the stock before the end of the year will be placed on a five percent dividend basis. The preferred stock has gone from 70 to 77. Standard Gas & Electric common, which was selling for $8 a share the first of the year, is now $15 a share, the stock being $50 par value, and the preferred, on which quarterly dividends of one percent, or half the regular rate, are being paid, has gone from 30 to 41. Steps are being taken by H. M. Byllesby & Co., the managers and controlling interest in Standard Gas & Electric, to put the company and its subsidiaries on a firm financial basis, and much progress along this line has been made. Earnings of the subsidiaries are showing good gains, and all indications point to a rejuvenation of this company as great as that of its sister company, Northern States Power, in which Standard Gas & Electric owns a 16 percent interest. Plans include a consolidation of funded debts, elimination of all short-time obligations and the creation of a new mortgage issue under which all requirements of the company and its subsidiaries may be met for years to come. Substantially all floating debt has now been paid and a large part of the short-time obligations has been funded.

Tennessee Railway Light & Power stocks also have made good gains since the first of the year. The common stock has advanced from 7 to around 12, and the preferred from 43 to 52. Earnings of the subsidiaries are showing large gains and, while it will be some time before the company will be in position to resume dividends on its preferred stock, good progress is being made towards that point. The company will require some more financing to provide for its floating debt and to secure the capital required to meet the great expansion of its business which is now demanding its full generating capacity, but with the present rate of earnings this can be accomplished without great difficulty. Two new generating stations, one steam and one hydroelectric are being erected.

These are only a few of the companies the stocks of which have shown

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great appreciation in the last six months. Others are Detroit United Railway stock, which has gone from around 70 to 119; Northern Ohio Traction & Light common, from 65 to 86; Ohio Cities Gas common, from 150 to 270; Columbia Gas & Electric, from 11 to 19, and a number of others. Many of these stocks have only started on their upward movement, and if the would-be purchaser of gas and electric light and power and electric railway stocks will keep close watch on the market and on developments in these companies, he will find that he can yet make many profitable purchases. With indications that in 1916 the central generating stations of the country will earn in excess of $400 000 000, or 16 percent more than in 1915, and with the generally bettered financial conditions of these companies, the investor will make no mistake in selecting their securities for investments.

AMERICAN PUBLIC UTILITIES COMPANY

American Public Utilities Company has sold to Philadelphia bankers $1 600 000 20 year, 6 percent secured bonds dated April 1, 1916. The bonds are the direct obligation of the company, which has outstanding $3 914 000 six percent preferred and $2 995 000 common stock. The bonds also are further secured by the deposit with the trustee of common stocks of subsidiary companies which cost the holding company $6 250 000 in cash and are now estimated as worth $8 500 000. American Public Utilities Company controls gas and electric light and power properties operating in a number of states. A subsidiary, the Wisconsin-Minnesota Light & Power Company is now constructing a 50 000 horse-power hydroelectric station on the Chippewa River in Wisconsin, and it is expected to be able to deliver power from this station January 1, 1917. A large part of the output of the new station has been sold under a long-time contract to the Northern States Power Company for distribution in St. Paul, Minneapolis and adjacent territory.

MIDDLE WEST UTILITIES COMPANY

Middle West Utilities Company, which operates electric light and power properties in fourteen states, serving 349 communities and a population of close to 1 000 000, is offering an additional amount of its 10-year collateral trust six percent bonds. There are $3 400 000 of these bonds now outstanding, with a total of $6 500 000 authorized for certification by the board of directors. They are a direct obligation of the company and secured by the deposit of mortgage bonds on the operated properties of the company. Their issue is restricted by indenture clauses in regard to net earnings of the subsidiaries, and they also are further secured by the deposit of a majority of the stock of each company, the bonds of which are deposited as collateral. In addition, there are substantially $11 000 000 in market value of common and preferred stock of Middle West Utility Company junior to these bonds. For the year ended April 30, 1916, it is estimated that gross of subsidiary companies will be $7 940 000, with net of $3 051 441, while Middle West Utilities Company will have net earnings, applicable to payment of interest on these 10-year bonds, of $1 265 600. As it will require but $390 000 to pay interest on the entire $6 500 000 authorized for certification, it may be seen that the interest will be covered more than three times.

INCREASED EARNINGS BY ELECTRICAL UTILITIES

Marked increases in earnings of the electric light and power and electric railways of the country were a feature of operation of these utilities for the first six months of 1916. While in the case of the electric light and power industry of the country there has been a steady increase in revenues even in the most depressed months of the first year of the European war, the electric railways of the country were not so fortunate and, with the depressed business conditions and the competition of jitneys, revenues of these utilities suffered severely almost up to the opening of 1916. The low point in rate of increase in earnings of electric light and power companies was reached in February, 1916, when an average gain of but two percent was shown over February, 1915, but from that time on there has been a steady increase in the rate of gain. By May, 1915, this rate of gain was up to 5 percent, and in September, 1913, it had reached 8.5 percent. For December, 1915, it was 12 percent, and in March, 1916, it was 18 percent. At present the rate of gain is running close to 18 percent, with an average gain in kilowatt-hour output of the central stations of the country of close to 24 percent.

Indications now are that for 1916 the central station companies of the United States will have total earnings in excess of $400 000 000, the largest by far in the history of the industry. A part of this large gain is due to the normal increase in the use of electric current for domestic and commercial lighting and for household power, but by far the greatest part is due to the greatly increased demand for power. Within the last year the central station companies have entered many new power fields, and with many of the companies their sales of current for power have been limited only by the generating capacity of their stations.

Especially have many of the companies developed the electric power field in the iron and steel industry. Several steel mills have been electrically equipped throughout, and generating companies at several steel manufacturing centers are now more than doubling their generating capacity to care for this class of business. The electrochemical industry also has been more largely developed in the last year in the United States than ever before. Electrical men say that the increased business which has been put on their lines has come to stay, and they expect that the last half of 1916 will show even greater progress in the central station industry from a revenue viewpoint than did the first half.

With the electric railway the practical elimination of the jitney as a competitive factor and the vast improvement in general business has resulted in good gains in revenues. The American Electric Railway Association estimates that for the first quarter of 1916 there was an average increase of 8.9 percent in gross revenues of the electric railways, while operating expenses increased 6.81 percent and net earnings gained 12.47 percent over the first quarter of 1915. Ratio of operating expenses to gross revenues, however, showed a decrease, being 63.11 percent of gross for the first quarter of 1915, while for the first quarter of 1916 it was 61.90 percent. Preliminary reports from a number of electric railways for the second quarter of the year indicate that the first six months of 1916 will show a gain of around 10 percent in gross revenues as compared with the first six months of 1915. The figures so far at hand also indicate that 1916 will be the best year from a revenue viewpoint in the history of the electric railway industry of the country. With the showing in earnings now being made by the electric light and power and the electric railway industry of the country it is not difficult to see why the securities of these companies have been steadily advancing since the first of the year.

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AMERICAN GAS & ELECTRIC

The rapid rate at which revenues of the subsidiaries of American Gas & Electric Company have been gaining is shown by the fact that, while the average rate of gain in the kilowatt-hour output of the central station companies of the country in 1915 was 10.9 percent, the average rate of increase in output of the generating stations of these subsidiaries for 1915 over 1914 was 33.8 percent. How rapidly new business is being connected to the lines of these companies is shown by the statement that in May, 1916, new business from 2347 customers, with an estimated annual revenue of $196 485 and a guaranteed annual revenue of $124 782, was taken on, while for the 12 months ended May 31, 1916, the new business attached to the lines of the subsidiaries embraced an estimated annual revenue of $1 480 209, with a guaranteed annual revenue of $673 774, coming from 23 057 customers. The new power business in May, 1916, was 5819 horse-power, and in 12 months, 45 239 horse-power.

One of the largest contracts recently taken for power by a subsidiary was that of the Ohio Light & Power Company for 4000 horse-power to be delivered to the Ohio Seamless Tube Company at Shelby, O. The current will be transmitted from the Tiffin generating station of the company, and eventually the load will be largely increased, as the tube company is preparnig to electrify its entire plant, which is now using about 6000 horse-power of steam units. The consumer under this contract takes the current at its high-tension delivery of 66 000 volts.

Because of large amounts being charged in operating expenses for renewals and replacements at some of the subsidiary plants, the usual large gain in surplus was not shown by the combined properties for April, 1916. Average gain in gross of the subsidiaries was 15.7 percent, in net 5.1 percent, and in surplus after charges 1.2 percent, compared with April, 1915.

NIAGARA FALLS POWER

Niagara Falls Power Company, with its subsidiary, the Canadian Niagara Power Company, closed its fiscal year in excellent condition. Combined gross of the companies increased $49 567, while total income was larger by $96 749 than for 1914. The surplus, after all charges, for 1915 was $1 028 058, compared with $969 543 in 1914. In regard to the operations for 1915 President Edward Wickes said:—"During the first half of the year earnings continued to be adversely affected by the business depression. A marked reversal of this condition occurred later, which particularly affected important industries served by the company. The demand for a larger output of their several products resulted in the higher load factor and increased sales of power. Gains in earnings in the later months of the year were sufficient to overbalance earlier decreases and to furnish substantial grounds for anticipating the reestablishment of the continuity of yearly increases shown prior to 1914. The great basic industries at Niagara Falls connected with our power houses are now applicants for further blocks of power which, under existing conditions, we cannot furnish."

During the year Canadian Niagara Power Company began installing in its completed power house three additional 12 500 horse-power generating units. The delivery of the turbines has been somewhat delayed, but shipments are to begin at once, and the work will proceed rapidly to completion. The board has authorized the rebuilding of the transmission lines to Buffalo, and about one-sixth of this work has been completed without interruption to service.

After nearly 20 years' participation in the establishment and use of Niagara power in Buffalo, the company has sold its interest in the Cataract Power & Conduit Company to the Buffalo General Electric Company, which has assumed all obligations of the Cataract Power & Conduit Company.

WEST PENN TRACTION COMPANY

West Penn Traction Company and its subsidiaries, including the West Penn Power Company, are reflecting in their improved earnings the wonderful industrial expansion in the Pittsburgh district. For April, 1916, combined gross earnings of the West Penn Traction properties increased $110 272 over April, 1915, while net increased $59 706, and surplus, after charges, $38 190. For the first four months of 1916 gross of the properties showed a gain of $374 692, with increases of $254 288 in net, and of $192 032 in surplus. The extensions and addition to the generating and transmission facilities of West Penn Power, announced when that company was organized, are being rapidly completed, and officials of the companies look for even larger earnings for the last half of the year than are being made in the first half.

NORTHERN OHIO TRACTION & LIGHT

The Northern Ohio Traction & Light Company in May had a gross increase of 98 721, and an increase in net available for common of $29 259. The month's net available for common was $93 419, or more than 1 percent. For the first five months of the year net available for common was $409 824, an increase of $223 491; this net is at the rate of 11 percent on common stock for the year.

CITIES SERVICE COMPANY

The gross earnings of Cities Service Company for May were $709 085, an increase of $421 720, or 147 percent, over May, 1915. The surplus for dividends was $644 851, a gain of $412 678, or 177 percent, and the balance for the common stock was $473 496, an increase of $372 150, or 367 percent. For the first five months of the current year the gross totaled $3 324 306, an increase of $1 533 168, or 86 percent, as compared with the corresponding period of 1915. The surplus for dividends amounted to $3 010 253, a gain of $1 491 227, or 98 percent, and the balance for the common stock $2 166 546, an increase of $1 301 684, or 150 percent. It is interesting to note that the balance for the common stock for the first five months of 1916 was greater than for the entire 12 months ending May 31, 1915. For the 12 months ending May 31, 1916, the gross earnings were $6 012 969, a gain of $2 060 169, equal to 52 percent, as compared with the 12 months ending May 31, 1915. The surplus for dividends was $5 308 171, an increase of $1 976 800, or 59 percent, while the balance for common was $3 548 624, registering a gain of $1 823 248, or 106 percent. The preferred issue dividends were earned 3.01 times, as against 2.07 for the previous period. This margin of safety places the preferred in an enviable position. While the earnings were at the rate of 21.98 percent on the average amount of common stock outstanding, as compared with 11.41 percent for the preceding 12 months, for the month of May, 1916, the balance for the common was at an annual rate of 31.46 percent. The substantial progress of the subsidiaries of the Cities Service Company is shown by the fact that gross earnings of these properties for the 12 months ending April 30, 1916, were $25 103 110, as compared with $19 757 594 for the preceding 12 months, an increase of $5 345 517, or 27 percent.

FINANCIAL SECTION

UNITED LIGHT & RAILWAYS COMPANY

United Light & Railways Company is now showing gains in earnings which, if continued over the end of the year, will result in better than 10 percent being earned for its common stock the current year. For 1916 it is estimated that the combined earnings of the operated properties will be in excess of $7 000 000, and that the surplus for the common stock of the holding company will be more than $700 000, or better than 10 percent on the outstanding issue. In 1915 United Light & Railways spent almost $900 000 for capital improvements at its various operated properties, and for 1916 appropriations for capital expenditures for extensions to services and additions to properties will total about $1 500 000. This large outlay is necessary by reason of the heavy demands being made for service on the subsidiary companies. United Light & Railways has an uninterrupted dividend record on its 6 percent preferred stock, but in the summer of 1914 the company suspended the quarterly dividends of 1 percent on its common stock. With earnings running as they now are, and with the company in its present excellent financial condition, there is no question but that the dividends on the common stock will be resumed soon, and it is expected in the Fall the stock will again be placed on a regular quarterly dividend basis.

H. M. BYLLESBY & CO. PROPERTIES

Standard Gas & Electric Company and Northern States Power Company, the two principal holding organizations controlled by H. M. Byllesby & Co., are reporting large gains in earnings of their affiliated properties. For April, 1916, consolidated gross of these properties showed gains of 9 percent over April, 1915, while the consolidated net was larger by 11 percent. Louisville Gas & Electric reported gains of 15 percent in gross and of 24 percent in net for the 12 months ended April 30, 1916, while Minneapolis General Electric Company is now reporting increases of 27 percent over a year ago.

REPUBLIC RAILWAY & LIGHT

Earnings of Republic Railway & Light Company, available for dividends on its common stock, are now running at a rate of more than 10 percent annually on the outstanding issue, and the board is considering the payment of an initial dividend on the junior issue. It is not probable that the declaration will be made until in the last half of the year, but at that time it is considered almost certain that the stock will be placed on a 1.25 percent quarterly basis. The company has an uninterrupted dividend record on its preferred stock, but has not as yet paid any dividends on its common stock. Republic Railway & Light properties are located in the Sharon and Youngstown districts, and consist of electric railway, electric light and power and gas properties. The corporate organization of the group was recently greatly simplified by the consolidation of a number of underlying companies and financing has been provided for a long period ahead. The company has just doubled the capacity of its principal generating station at Lowellville, O., bringing it up to 40 000 horse-power. The wonderful industrial expansion in the Youngstown and Sharon districts has resulted in large gains in earnings of Republic Railway & Light subsidiaries, their combined gross for April, 1916, showing a gain of 38 percent over April, 1915, while net increased 49 percent and the surplus for dividends 93 percent.

NEW BOOKS

"Property Insurance; Fire"—Lester W. Zartman and W. H. Price. 408 pages, size 5x7 inches. Published by Yale University Press. Price 2.25.

This book comprises a series of lectures on fire insurance by different authors. These lectures are intended to provide a comprehensive understanding of the fire insurance business, and covers history, contracts and protection. It is with the latter considerations that the engineering profession should be most concerned. It is one thing to erect an expensive plant and it is another to protect it against loss at minimum expense. The problem of securing low rates for fire protection has not been taken up in the universal manner it deserves. In the aggregate enormous savings could be effected. The manager and engineer should have a full knowledge of the basis of insurance contracts, the principle of rate-making, the co-insurance clause, etc. These lessons are often learned after some sad experience and heavy losses have been suffered. In these enlightened days the progressive owner takes advantage of the experience of others, and in this book will be found the opportunity for one to familiarize himself with the underlying factors of the fire insurance business.

E. D. D.

"Ozone—Its Manufacture, Properties and Uses"—A. Vosmaer. 197 pages, 75 illustrations. Published by D. Van Nostrand Company, New York City. For sale by THE ELECTRIC JOURNAL. Price $2.50.

An excellent discussion of the properties of a little known substance. But little practical use has been made of ozone for the purification of water or in industrial chemistry in America, although there are many applications to the purification of air, especially in restaurants and hospitals. In Europe, however, ozone is extensively used in the sterilization of drinking water, the author giving a list of twenty-six installations in France, four in Roumania, seven in Germany, six in Italy, three in Russia, one in Austria, one in Spain, in addition to three in South America. These installations include some of the most important cities in Europe, the largest, at Paris, having a capacity of 24 000 000 gallons of water sterilized per 24 hours. In addition to the successful applications which have already been made, the author points out the possibility of a more extended use of ozone as an oxidizer in many industrial and chemical fields. Ozone is a most energetic oxidizing agent at ordinary temperatures and can accomplish reactions never performed by oxygen under similar circumstances. Its principal opportunity is, however, in organic chemistry rather than in the inorganic field. The book is divided into four parts. The first deals with the early history, constitution, nature, occurrence and properties of ozone and tests for its presence. The second part deals with its manufacture, principally by electrical methods. Electrical discharges are treated fully, both from the theoretical and practical standpoint, including a discussion of the influence of the medium through which the discharge gases; the influence of the electrodes; the effect of the kind of current, with respect to voltage, frequency, wave form, direct or alternating; the influence of the electric circuit; the influence of radiation, magnetic and electric fields; and the influence of a dielectric between the electrodes. Various types of ozonators are described in detail. Part III describes the use of ozone in the purification of water; purification of air; therapeutic uses; and its use in industry. Part IV gives a list of American patents bearing on ozone and an extensive bibliography. This book gives a comprehensive and, we believe, authoritative treatment of the subject. It is unique in that the author frankly confesses his individual preference for the apparatus of certain manufacturers, a confession which is unusual and which to many will seem out of place in a work of this nature.

C. R. R.

"Principles of Electrical Design"—Alfred Still. 365 pages, 145 illustrations. Published by McGraw-Hill Book Company. Price $3.00.

This work by the professor of electrical design at Purdue University is intended mainly for students in electrical engineering. No attempt is made to deal adequately with the mechanical problems involved in the design of electrical machinery. Detailed design sheets are given for the use of students in going through various calculations of elementary machines. It is now generally recognized that actual design has very little place in an engineering course except possibly as a means of showing the application of fundamental principles. It is also recognized that only a very small percentage of graduates in electrical engineering become actual designers, so that for the majority of students this subject is not of vital importance. Certain fundamental ideas, however, can be applied in such a course, including the review and application of laws and rules already studied, which may be of considerable assistance to the student in mastering his subject. The general scope of the work is much the same as other books on similar topics, although the method of treatment is original. Designs are given for both direct and alternating-current machines.

PERSONALS

Mr. Aaron Dean, formerly resident manager of the New York office of the Union Switch & Signal Company, has been appointed special representative, with headquarters in New York. Mr. W. P. Allen has been appointed resident manager.

Mr. H. O. Swoboda, consulting engineer, Empire building, Pittsburgh, has been retained by the borough of Monaca, Pa., as consulting engineer in conducting negotiations with the local lighting company.

Mr. D. R. McNeal has resigned from his position with the Westinghouse Machine Company, East Pittsburgh, to enter the employ of Dravo-Doyle, of Pittsburgh, headquarters in Philadelphia.

Mr. Edmund J. Henkhe, for over eight years with the Russian and British Westinghouse companies, and more recently assistant to the president of the International Textbook Company, of Scranton, Pa., has resigned from the latter concern to become assistant general manager in charge of engineering and sales department of the Thomson Electric Welding Company, of Lynn, Mass.

Mr. F. W. Brook, formerly general manager, has been elected to succeed Mr. J. C. Hutchins as president of the Detroit United Railway Company.

Mr. E. J. Burdick has been appointed assistant general manager of the Detroit United Railways Company. He was formerly with the Brush Electrical Manufacturing Company of Cleveland, and later with the Westinghouse Electric & Mfg. Company, where he remained until he became associated with the Detroit Electric Railways in charge of electrical equipment.

Mr. R. E. Carlson, formerly connected with the industrial sales department of the Westinghouse Electric & Mfg. Company, Chicago office, has resigned to accept the position of vice president and sales manager of C. A. Hoppin & Co., engineers and constructors, Peoria, Ill.

Mr. F. L. Francisco, senior member of the engineering firm of Francisco & Jacobus, consulting engineers, New York City, has been appointed by Mayor Thompson, of the city of Chicago, as the city's representative on the Board of Supervising Engineers, Chicago Traction. A little more than a year ago Mr. Francisco began a study of electrolysis conditions in Chicago and thus has already been in close touch with the details of the street railway system of Chicago.

Roller - Smith Company, 233 Broadway, New York, has recently published its Bulletin No. 300, describing its portable direct-reading slide wire ohmmeters. These instruments are made up in both the telephone and galvanometer types. Copies of this bulletin will be sent on request.

Mr. J. N. Hopwood, superintendent of power for the West Penn Traction Company, Pittsburgh, Pa., has resigned to accept the position of sales manager of the stoker and specialty department of the George J. Hagan Company, Pittsburgh.

Mr. G. T. McFarland, New England district engineer of the automobile equipment division of the Westinghouse Electric & Mfg. Company, has resigned to accept the position of manager of the Ashwell Service Stations, Hartford, Conn., dealers in all kinds of electrical equipment for automobiles.

NATIONAL EXPOSITION OF CHEMICTL INDUSTRIES

The week of September 25 will be a very important one in the history of chemistry and electrochemistry in America, for the Second National Exposition of Chemical Industries will be held in New York all through that week. The American Electrochemical Society will meet in New York during the same week, September 28, 29 and 30. The outline of the program has just been announced:

Wednesday, September 27—Evening, general reception, with registration at the Chemical Exposition, Grand Central Palace.

Thursday, September 28 — Forenoon, reading and discussion of papers; general subject, "Made in America.' Afternoon, visiting the Exposition. Evening, complimentary smoker. An invitation will be extended to the members of the American Chemical Society and other visiting chemists and engineers.

Friday, September 29 — Forenoon, reading and discussion of papers. Afternoon, visiting the Exposition. Evening, subscription dinner-dance.

Saturady, September 30 — Forenoon, reading and discussion of papers. Afternoon, visiting the Exposition.

ILLUMINATING ENGINEERING LECTURE COURSE

The Illuminating Engineering Society has decided to hold a second series of lectures at the University of Pennsylvania, Philadelphia, from September 21-28, inclusive, immediately following the annual convention of the Illuminating Engineering Society. The course will include about twenty lectures on the principles of illumination and various aspects of lighting practice. Whereas the 1910 course, at Baltimore, emphasized the science of illumination, the new course will emphasize the art of illumination. Associated with the lectures will be an exhibition of the latest developments in illuminating appliances, including lamps, accessories, photometers, etc., together with novel applications of light. In connection with the lecture course there will be an inspection tour. This will be laid out in such a manner as to afford the maximum of educational value with a minimum of time and expense. It will include visits to manufacturing establishments, laboratories, lighting companies and notable installations.

Preliminary List of Subjects — (a) General—(1) "Illumination Units and Calculations," by A. S. McAllister; (2) "Modern Photometry," by Clayton H. Sharp; (3) "The principles of Interior Illumination" (two lectures), by J. R. Cravath, chairman; (4) "The Principles of Exterior Illumination," by Louis Bell; (5) "Color in Lighting," by M. Luckiesh; (6) "Architectural and Decorative Aspects of Lighting," by Guy Lowell; (7) "Recent Developments in Electric Lighting Appliances," by G. H. Stickney; (8) "Recent Developments in Gas Lighting Appliances," by R. F. Pierce; (9) "Modern Lighting Accessories," by W. F. Little.

(b) Special Lectures on Interior Illumination—(10) "The Lighting of Factories, Mills and Workshops," by C. E. Clewell; (11) "The Lighting of Offices, Stores and Shop-Windows," by Norman Macbeth; (12) "The Lighting of Schools, Auditoriums and Libraries," by F. A. Vaughn; (13) "The Lighting of Churches," by E. G. Perrot; (14) "The Lighting of the Home," by W. H. Jordon; (15) "Railway Car Lighting," by G. E. Hulse.

(c) Special Lectures on Exterior Illumination—(16) "Street Lighting" (two lectures), by P. S. Millar and C. F. Lacombe; (17) "The Lighting of Yards, Docks and Other Outside Works," by J. L. Minick; (18) "Headlights, Searchlights and Projectors," by E. J. Edwards; (19) "Sign Lighting," by L. G. Shepard; (20) "Building Exterior, Exposition and Pageant Lighting," by W. D'A. Ryan.

The price of tickets for the lecture course has been fixed at $25. It is desired to ascertain, as early as possible, the approximate number of people who will take advantage of this lecture course. For information or application blanks address Mr. Preston S. Millar, Chairman, Eightieth street and East End avenue, New York City.

NEW BOOKS

"Central Station Management"—H. C. Cushing, Jr., and Newton Harrison. 307 pages, size 4x6 inches. Published by D. Van Nostrand Company, New York City. Price $2.00.

The authors in their treatment of this subject have logically taken up the broader problems of the electric light industry. This field has a great many ramifications and involves extensive details. The many branches have been presented in specific manner in various technical journals and the *Proceedings of the National Electric Light Association* and, therefore, much information is on file. However, there is a lack of books taking up these problems in a composite fashion, and the authors' contribution will aid in filling a long-felt want. Among the topics which are particularly discussed are rates, efficient illumination, public service regulation, plant economies, district steam heating, conduct of sales organization, etc. There are in all 32 interesting chapters, which should be profitable to those who are striving to increase their perspective of the central station situation. E. D. D.

"The Engineer in War"—P. S. Bond. 187 pages, 72 illustrations. Published by McGraw-Hill Book Company, New York City. Price $1.50.

In these days of co-ordinated trench warfare over a front of hundreds of miles, of aeroplane scouts, wireless communication automobile transportation and, above all, of extensive artillery combats, requiring months of preliminary industrial preparation, it is evident that the engineer plays a prominent part in modern warfare, both at the battle front, in the lines of communication and in the munition and equipment factories at the base of supplies. "The Engineer in War," by Major P. S. Bond, of the Corps of Engineers, U. S. Army, outlines to civilian engineers the activities of the American army engineer and the part that the civilian engineer can be quickly trained to perform. Military engineering is essentially different from commercial engineering in that cost and, in fact, nearly all other considerations, are sacrificed to rapidity; the structures are usually built to meet a temporary need and are constructed by temporary makeshifts; labor in the form of troops is plentiful, and is used where machinery would be used by the civilian engineer. The economics of military engineering are brought out, together with their application to the more common military engineering feats, such as bridge and road building, field fortification and siege operations, demolitions, reconnaissance and surveying, sanitation and mobilization. The introductory chapter discusses the present military policy of the United States, and the concluding chapter treats of the military obligations which good citizenship imposes on the civilian engineer. An elaborate bibliography and glossary of military terms is appended. From the standpoint of the reader it is unfortunate that the appearance of so excellent a work should be spoiled by the excessive use of bold-face type, intended evidently to emphasize, the net result being, however, confusing rather than emphatic. The electrical engineer will regret that the use of field telephones and portable wireless outfits is entirely neglected. C. R. R.

"Value for Rate-Making"—Henry Floy. 322 pages, one insert diagram. Published by McGraw-Hill Book Company. Price $4.00.

This book may be considered as supplementing the author's first book, entitled "The Valuation of Public Utility Properties," and is an attempt to further emphasize a number of essential principles and to aid in standardization. Practically every utility property includes a certain number of non-physical elements which should be evaluated and allowed in addition to the tangible elements. This is a phase of the subject on which there is a great variety of opinion, and the author's long experience in this line of work should carry considerable weight. He gives numerous court decisions embracing typical cases as a means of showing the general trend in valuation work. Among the topics discussed most thoroughly are,—the cost of reproduction; land, paving and water rights; franchises, working capital and bond discounts; going value; absolute and theoretical depreciation. Public utility men and public service commission officials will doubtless find this work of considerable value as summarizing present-day conclusions on the subject.

"Theory and Calculation of Alternating-Current Phenomena" — Charles P. Steinmetz. 480 pages, 222 illustrations. Published by the McGraw-Hill Book Company, New York City. Price $4.00.

This is the fifth edition of this work, the original of which appeared nearly twenty years ago. The fourth edition was a volume of 746 pages. Since that time it has been found necessary to divide the work into three volumes in order to treat adequately the numerous advances in electrical engineering. The present book includes under the old title the discussions of the most common and general phenomena and apparatus, and it is planned to present two new volumes under the titles, "Theory and Calculation of Electric Circuits" and "Theory and Calculation of Electrical Apparatus," the three books embracing the general scope covered by the original first edition. In the present edition certain changes have been made in the method of vector representation in accordance with the decision of the International Electrical Congress at Turin. The general arrangement and style is similar to previous publications by the same author.

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The Constructive Analyst

Every field of industrial activity is calling for the man trained in the art of analytical thinking—the man who with calm deliberation logically separates the important from the non-essential and produces facts, not opinions; all the essential facts, not only the most obvious ones; new ideas, not old traditions. He is called an engineer, but he needs not engines with which to ply his art. Agriculture, law, medicine, salesmanship, business management, research of materials, design and construction of machines, organization of men, purchasing, accounting—all demand the analytical, unprejudiced, thorough man. Indeed, it is doubtful if men without this characteristic can advance beyond mere routine work.

The best known methods in nearly every walk of life are crude, clumsy and wasteful, and the whole world is looking to the constructive analyst to find better ways—short cuts in time and material—that life may be more abundant for all mankind. A young man about to enter industrial life should investigate, first of all, the various branches of the profession he has chosen. He should apply engineering methods in determining his life work and in fitting himself to it. Success to any considerable degree comes only to him who masters some subject with distinction. Be sure, however, that you find the best subject for you.

The important thing is to select your special work with such care that it will always be your chief pleasure; then failure, in whatever terms you choose to measure it, will be impossible. On the other hand, calmly to follow the chance demand, the advice of friends, or the lure of immediate wealth, is dangerous to any success. There is nothing inherent in any worthy task that makes it less desirable, less respectable or less profitable, save the way in which it is performed. C. R. DOOLEY

Utility Capitalization Records

Public service commissions were appointed originally to protect the public from so-called "corporation greed." They were expected by the voter to reduce rates and to squeeze the water out of swollen capitalizations. In some cases this result has been accomplished. But after a number of years of corporation baiting on the part of the uninformed public and vote-seeking politicians, and of careful study of the public utility question by the various commissions, the latter are finding frequently that protection must be accorded in both directions. A reduction in rates may be made arbitrarily up to the point of confiscation, but if such a reduction affects adversely the borrowing power of the utility, the best interests of the public are not thereby served, as the inevitable result is poorer service and a cessation of extensions and improvements. The attitude of the Maine Commission on this point is explicit, as expressed in its decision in the Lewiston, Augusta & Waterville Street Railway case:—

> "And while the commission wishes to assure the great army of patrons of public utilities in the state that it will be vigilant in securing for them adequate service at reasonable rates, it is equally desirous of making it plain that capital invested in construction, development and extension, and especially in planting them in sections not now served, will receive consideration sufficiently favorable to make it an object to come here."

Similarly, Walter A. Shaw, engineering member of the Illinois Commission, has recently filed an opinion concerning past capitalizations:—

> "I do not believe that it is the intent of the law that this commission should undertake to correct all the evils that grew under past unregulated conditions, nor that this commission act retroactively, so to speak, by requiring valuations of all existing utility properties when allowing additional securities to cover additions, betterments, etc., in all cases where previously existing outstanding securities may exceed the value of the tangible property. Should the commission adopt a policy of entering upon valuations whenever security issues are involved, it is predicted that a general financial upheaval, as far as the public utilities of the state of Illinois are concerned, would result therefrom. In the final analysis the public would be the loser. I believe that the law as written intends that this commission should see that new security issues of existing utilities represent actual property, and that the law does not contemplate that this commission should concern itself with past issues for the purpose of correcting the evils of former years."

One great good that has been accomplished by the commissions has been to awaken the utility officials to a more thorough study of the financial standing of their organizations. A corporation which has made a careful analysis of its financial standing, and which is in a position to demonstrate that it is providing good service at as low rates as are warranted by local conditions, is not liable to have any serious misunderstanding with the public service commission. There will, of course, continue to be complaints from the ignorant and from those of socialistic tendencies who do not seem to comprehend, for instance, why street car conditions are different in Pittsburgh or Cincinnati from those in Cleveland or Detroit. But students of the public utility situation, and the public service commissions in general, have shown themselves willing to accept the figures of the corporations where they are available, except when they are manifestly prepared for the occasion. Under the latter circumstances, the affairs of a utility company are liable to be examined more circumspectly than would be the case if a thoroughgoing analysis had previously been prepared and made available for inspection on request from the proper authorities. CHAS. R. RIKER

Technical Training for Engineers*

B. G. Lamme
Chief Engineer,
Westinghouse Electric & Mfg. Company

THE AUTHOR of the following article has had a wide experience in the education of so-called "educated" men. Almost since his entrance into the employ of the Westinghouse Electric & Mfg. Company, early in 1888, he has given a considerable part of his time to the development of the more promising young engineers with whom he came in daily contact. Being himself extremely fond of the analytical side of his work, and also recognizing its fundamental importance, he has been very free in imparting his methods, data and experience to his associates and assistants, thus in fact, although not in name, becoming an educator along advanced lines. He always has been in search of young men of the right turn of mind whom he could develop into "stars" in his profession, and many men prominent in the electrical industry today can speak with pride of the training they received while associated with him. Recognizing that the engineering development work of the manufacturing companies is becoming increasingly difficult from year to year, he has given special attention, during the past several years, to the selection and training of graduates of the technical schools who show, to an unusual degree, certain characteristics and aptitudes which he believes to be necessary in maintaining the high standard of the Westinghouse company in the engineering field. In other words, he is applying his analytical methods to men very much as he has applied them to apparatus and principles in the past years.—(Ed.)

IN THE earlier days of the Westinghouse Electric & Mfg. Company many young technical students were taken directly into the various departments and there trained. But in time the student problem became so large and important that an educational department was developed to meet in a systematic manner the growing needs of all departments. This educational department works in conjunction with the other departments in training men and in placing them where they will have opportunities in accordance with their special abilities. While the educational department supervises the student course, yet much of the training is through representatives of the commercial, manufacturing and engineering departments.

The following remarks represent the writer's own personal opinions, based largely upon a comparatively wide experience with the young engineers who have entered the student's course during the past five or six years. In that time this company has taken into its educational department over one thousand graduates of technical schools from all over the United States and Canada. Of these, several hundred have wished to specialize in engineering, while the aim of the others has been toward the manufacturing and the commercial lines, both of which require good technical training. The electrical salesman of today is quite technical, regardless of how he got his training. Also the complexities of the electrical business of today require many high-class technical men in the manufacturing departments. As to engineering, it goes without saying that those who follow this branch of the electrical business should be technical men, if they are to advance very far. In consequence, the Westinghouse Company takes on technical graduates almost exclusively for its student's course, regardless of what branch of the electrical business they expect to follow.

The writer's personal experience has been very largely with those students who expect to follow the engineering branch of electrical manufacturing. During the past few years he has come in contact with practically all those who leaned toward engineering work. One of the most important considerations in the engineering student problem has been that of fitting the men to the kinds of work for which they are best adapted. In former years this was done in a more or less haphazard manner by trying the men out in different classes of work to see whether they would make good. This procedure proved so unsatisfactory that it became necessary to adopt some method of classifying the students according to their aptitudes and abilities, and then try each one out on that line of work for which he seemed to be best fitted. Obviously, this method was in the right direction, but the primary difficulty lay in determining the characteristics of the individual students. The writer has spent quite a considerable amount of time in the past few years in studying the characteristics of the students to see whether their natural and their acquired abilities can be sufficiently recognized, during the preliminary stages of the work, to allow them to be properly directed toward that field in which they will make the best progress. In this study, in which hundreds of young men were analyzed with regard to their characteristics, many very interesting points developed, quite a number of which have a direct bearing on the subject of technical training. In the first years of this study the results were very discouraging, due largely to the fact that the young men had been brought to us in a wholesale way, regardless of their characteristics or their suitability for our engineering work. Many of them had no ideas whatever in regard to the kind of work for which they were fitted. Apparently, the man who had not, at least partly, made up his mind as to his preferences or his capabilities for some given line of endeavor by the time he had gone through four years of college and then entered our course, had much difficulty in making up his mind after he had been with us a year or two. It developed, in many cases, that he was lacking in decision. This was a very predominant fact in the first few years after the writer had gotten into

*Prepared from notes of addresses before the Pittsburgh Section, A.I.E.E., and the National Association of Corporation Schools.

this work more actively. After a careful study of the situation it was recommended that an attempt be made to get a different class of college men, namely, those who had more definite ideas as to what they wanted and what they were fitted for. This policy was tried, and with great improvement in the grade of men obtained. It is principally from the study of these later men that the writer has been able to draw some of the conclusions which are here given.

One of the most prominent features which has developed from the study of these young men is that in practically all cases the most valuable aptitudes or characteristics which they have shown were possessed by them long before they entered college. In fact, many of them have apparently possessed such aptitudes, more or less developed, from comparatively early childhood. For example, the best constructing or designing engineers all had a strong tendency toward the construction of mechanical toys and apparatus in childhood. In regard to such characteristics, the schools and the colleges have merely directed and developed to a greater extent what is already there. From this vewpoint, therefore, the college simply develops. If the tendency isn't there, it would seem *that there is but little use to try to develop or cultivate it.* Viewed from this standpoint, quite a large percentage of the young men who take up engineering courses in college are quite unfitted for such work. Therefore, one function of the college should be to sort out and classify the young men according to their characteristics, to discourage them from following along any line of endeavor for which they have no real aptitudes, and to direct them into more suitable lines. This applies particularly to technical schools. It might be said that in our present educational system the usual method is to educate the young men and then select the real engineers, this selection being made afterwards through bitter experience. The ideal method, apparently, would be first to select the real engineers and then to educate them. In other words, those who show a natural aptitude for engineering should be educated along technical lines.

In the technical school one of the first efforts should be toward finding the student's natural aptitudes. Some boys apparently have no leaning toward any special line of endeavor. On the other hand, many boys really have some inherent preference which, however, may not have been strongly enough developed to stand out prominently. Too often his real preference has been entirely neglected or even discouraged. In the writer's own case, as a boy, he was very frequently and severely criticised for his inclination to "waste valuable time" in trying to make what were called "useless things." However, fortunately for himself, no real pressure was brought upon him to prevent him from following his preferences or tendencies, and eventually the "call" was so strong that it took him into the very work which he wanted above all else.

On the other hand, the boy may express a preference for a line of work for which he is entirely unfitted. In other words, this preference may not be based upon natural aptitudes or characteristics and is not a real "call." It is these boys, who are unfitted for the lines which they have chosen, who are a real handicap on their classmates. The class never moves along faster than its average man, and very often at the speed of the poorest men. If these poorest men were eliminated, naturally the progress would be much faster. Apparently the present methods of training have not yet overcome this difficulty, although very many teachers recognize the evil, and are attempting to correct it. This will be referred to again later.

Coming to the technical training of the students, experience indicates that too much specialization is a mistake. He gets enough of that in after years. What is needed is a good, broad training in fundamental principles. In engineering matters, a thorough grasp of such fundamentals is worth more than anything else. By fundamentals is meant basic principles or facts. These should not be confused with theories or explanations of facts. A fact is basic, and does not change, although the theories which explain it may change many times. A thorough knowledge of basic principles will enable a direct answer to be made in many cases, even where the conditions of a problem may appear to be very complex. Take, for example, the perpetual motion fallacy in its various forms. A perpetual motion scheme may be made so complex and involved and may include so many principles and appurtenances that the best analyst may be more or less puzzled to explain the various relations clearly. But by applying the principle of conservation of energy no further explanation is necessary. This one fundamental fact covers the whole case. In the same way a thorough grasp of some basic principle will often clear up the most complex problems or situations and will allow a conclusive answer to be made. With such a grasp of fundamentals, one is not liable to believe that a "pinch" of some wonderful new powder or chemical, mixed with a gallon of water, will give the equivalent of a gallon of gasoline, and at the cost of a few cents. And yet this fallacy "breaks loose" periodically, and is given wide circulation in the news of the day. What is needed in such cases is a little knowledge of fundamental principles.

This very grasp of fundamentals accustoms the boy to think for himself. In other words, it develops his *analytical ability.* As one educator mentioned to the writer some time ago, "If a boy has analytical ability, there is hope for him; if he has none, he is 'punk.'" By analytical ability is not necessarily meant mathematical ability with which some people are inclined to confuse it. By analytical ability is meant the ability to analyze and draw correct conclusions from the data and facts available. This faculty can be cultivated to a considerable extent, although, in the writers' opinion, it originates rather early in life. This is considered by many as the first and foremost characteristic that an engineer must have, and therefore the schools should expend their best energies in this direction.

Allied with a grasp of basic principles is the requirement of a physical conception of such principles as distinguished from the purely mathematical. This can be cultivated, as the writer's personal experience with many students has indicated. As a concrete example of the value of a physical conception the following may be cited:—Three electrical engineers, familiar with induction motor design, are given some new problem regarding the action of an induction motor. One of them immediately thinks of a "circle diagram;" the second thinks of a mathematical formula; the third thinks of flux distributions and conductors cutting them at certain speeds, etc. Assuming equal mathematical skill for these three men, the one with the physical conception of the conductors cutting fluxes has a broader means for attacking the problem than either of the others can be said to have. He can tackle a new condition with better chance of success, as he goes back to the fundamental principles of the apparatus. He thus may create, confidently, new formulae and diagrams to meet new conditions and problems.

This physical conception is closely related to the development of imaginative powers, and without such powers highly developed no engineer can expect to advance far in his profession. The man with originality, resourcefulness or with the constructive faculties well developed, or the man who "can see through things" readily, must have strong imaginative powers. This faculty also should be developed to the utmost, but should also be directed. It begins early in some children, but, unfortunately, instead of being directed, it is too often discouraged, both at home and in the school. If the boy in the public school develops a new method of solving a problem, or reaches any conclusion by other than the well-established routine way, he is criticised more often than encouraged for his departure from the beaten track, or rather his instructor's particular methods.

As stated before, the student should be well trained in fundamentals or basic principles. In many branches of engineering this means that he should have a good training in mathematics. Most of the graduates of the technical schools are woefully weak in mathematics. Apparently this is not due entirely to lack of mathematical ability on the part of the students, but largely to defective training in their earlier work. One great defect in many colleges is due to passing the entrants, in algebra and trigonometry, on the basis of their high school training. In most cases this early training in algebra is very defective, as sufficient skill is not developed in the student and the practical side is largely neglected. Algebra and its applications to geometry, trigonometry, etc., should be taught in a more practical manner in the engineering college course, as a foundation for the higher engineering mathematics. The higher the structure is to be, the stronger must be the foundation. If the engineering student is not sufficiently practiced in these elementary mathematics, then he should be drilled specially as a step to further engineering work. In the practical engineering work, beyond the college, skill in the use of algebra and trigonometry is of relatively much more importance than practice in the higher mathematics, for it is needed one hundred times where the other is used once. In the writer's experience with engineers he has reached the conclusion that the principal reason why mathematics are not used more in everyday work is because the average engineers have not the necessary skill. Most of them claim that they have become "rusty" in such mathematics through disuse. However, in many cases, this excuse is worse than none at all, for the occasion for such mathematics exists in practical engineering work and has been there all along.

In the education of the engineer, higher mathematics forms a very valuable part of the training. One of its uses is to show how one can do without it. In other words, if properly taught, it gives a broader grasp of methods of analysis; it tends to fix certain fundamental principles. However, as a tool in actual engineering work it is seldom required, except in rather special lines. The higher mathematics might be looked upon as a fine laboratory instrument or tool, to be used on exceptional occasions, while the ordinary mathematics should be considered as an everyday tool in engineering work, and should be ready at hand at all times.

There has been quite a fad for specialization in engineering training. The writer's personal opinion is that specialization in college training is not advisable, except possibly in a very general way. There has been a false idea in many schools that if a man specialized along some individual line of work it would advance him more rapidly when he leaves school for active work. The writer almost never asks the student in what field he specialized. It is desired to know whether he is a good analyst, if he is fairly skillful at mathematics, if he has the imaginative faculty and what goes with it. Has he initiative, resourcefulness, etc.? Is he a man with a broad grasp of general principles rather than one who has made a special study of one individual subject?

In college training the time spent on commercially practical details is usually largely wasted, as it may give the student entirely wrong ideas. When a young man says that he has had a course in practical design and is positive that he can design, the chances are about ninety-nine out of one hundred that he knows nothing about the really fundamental conditions in practical design. The chances are that he doesn't even know the real starting point in making up a commercial design. Even worse, if he has taken such training seriously, he may have to "unlearn" many of his ideas, if the use of this term is allowable. The mental training and the aid in grasping principles which he may have obtained through his school design is, of course, worth something, but in many cases the same time expended in other channels may produce larger results. Teaching of design should, therefore, be for the purpose of exemplifying principles rather than practice. There are, of course, some lines of specialization in colleges which lead directly to prac-

tical results afterwards. Research work is one of these. However, it is probable that if a large part of the time given to research work by the student in college were expended in acquiring a broader foundation in fundamental principles the results would be better in the end.

As referred to before, there has been one serious defect in our systems of technical training today, namely, it holds back the leaders and pushes the laggards, thus tending toward mediocrity as the general result. There should be some system in colleges for weeding out the "negatives" in any given line of endeavor. Many of these are simply "misapplications," to use a manufacturing company term. In some other lines they may be highly successful.

In an ideal engineering course each student should be pushed to the utmost of his capabilities. One solution of this problem would be for each teacher to assign a certain amount of extra work to his students individually, and they should report to him individually on such work, explaining to him fully what they have accomplished. Each man thus could be pushed along independently of his fellows. The weaknesses of the individual men would soon appear. If, for example, it develops that certain of the students are behind in the necessary mathematics, then steps could be taken to correct this defect. Each student would have to think more for himself and would be put more or less upon his own resources. His various characteristics could be studied and developed. He should be made to work out and apply fundamental principles. He would thus practice using his own mind. As soon as it develops that he has no mind of his own, then he could be dropped. In such a course of teaching the advancement of each man would be dependent upon himself, to a large extent. At this point a principle of mechanics can be applied rather aptly. In machines a force does work in overcoming resistance. In man the same principle holds true. No matter how much force a man may have, if no resistance is presented, no result is accomplished. And if the force is small, then the result is also liable to be small. But a smaller force overcoming a larger resistance may result in greater accomplishment than a larger force with but little resistance. An unusually brilliant boy with too small a task set for him may accomplish little. His task must be enlarged to suit his abilities; for, as in machines, to obtain the greatest result the resistance, or task, must be commensurate with the force acting. Unfortunately, many good men of great capabilities accomplish practically nothing, through too little resistance, due to life being made too easy for them.

Such a course of "forcing," as indicated above, might be difficult to apply in many of the schools as constituted today. But the writer's personal experience indicates that the better class of men will develop rapidly under such treatment, while the laggards are eliminated more quickly. He has tried this system in general on many graduates from the technical schools and unusually satisfactory results have been obtained.

All of the foregoing points to the fact that the mere accumulation of knowledge is not a training, nor an education. The old saying that "knowledge is power" is not technically correct any more than is the statement that torque (or force) is power, to use an engineering comparison. Torque, or force, is not power, but *torque in motion* is power and, to continue this comparison, *knowledge in motion*, or in action, is power. Activity in some form is one of the essential factors.

To sum up, the colleges should aim to develop the student's characteristics, as far as practicable. They should aim to develop analytical ability, imaginative faculty, ability to do independent thinking. They should teach fundamental principles, and the course of teaching should be such as to give the individual student a real grasp of such principles. A broad general training is most desirable for the man who has the ability to do something in the world.

Use of Metal Slot Wedges in Induction Motors

WITH SPECIAL REFERENCE TO THEIR EFFECT ON PERFORMANCE

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IN THE following short article it is not possible to go into details of mathematical derivations or technical explanations in connection with this subject. The purpose is rather to give in brief a clear understanding of the effect on motor performance of different types of wedging and slot construction. Where some derivations or technical explanations are necessary, these are given as concisely as possible.

AS ELECTRICAL apparatus of the rotating type has developed through various stages to the present designs, there has been a general tendency towards the use of open slots in both the stationary and rotating members (the latter in phase-wound rotors only), which permits the use of form-wound or pulled coils which can be inserted in the slots as a unit and also readily removed. There are exceptions, of course, in the cases of the smaller motors and special ratings, such as two-pole motors, where the partially closed slot is used and the winding threaded in, or the overhung tooth is used and the coils placed in the slots in two halves.

The form-wound coils can be handled more readily in winding, removing and repairing, since the whole coil is as one piece, an advantage which brings the open-

slot construction into favor with large users of induction motors who have a proportionately large amount of repair work which must be accomplished in the shortest possible time. However, from the standpoint of motor performance, partially closed or overhung tooth slots have an advantage over open slots. The use of metal wedges in open slots, however, practically realizes this same advantage, and at the same time does not materially alter the advantages of the open-slot construction. Slots with metal wedges, with fibre wedges and

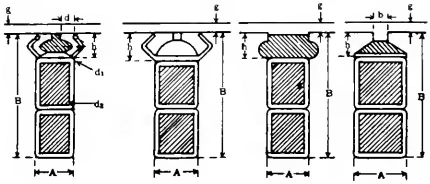

FIG. 1—THREE-PIECE METAL WEDGE IN OPEN SLOT
The outside members are of steel and the center member of brass.
FIG. 2—ONE-PIECE SLOTTED STEEL WEDGE IN OPEN SLOT
FIG. 3—OPEN SLOT—FIBRE WEDGE
FIG. 4—PARTIALLY-CLOSED SLOT—FIBRE WEDGE

with partially closed top are illustrated in Figs. 1, 2, 3 and 4. There are various other types of metal wedges, but these are typical and illustrate the general arrangement. The metal wedges are insulated from the teeth, as otherwise they would short-circuit the laminations, and the advantages of a laminated core would be lost.

Various problems were encountered in the development of these wedges, but they have one after another been solved, and the wedges as now perfected are beyond criticism from the operating and commercial stand-

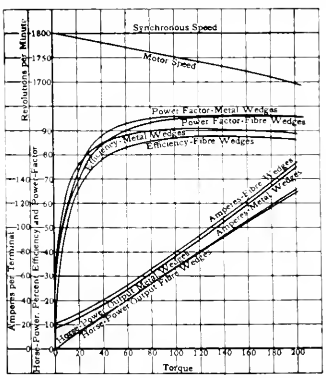

FIG. 5—PERFORMANCE CURVES
40 hp, three-phase, 60 cycle, four-pole, 220 volt, 1740 r.p.m. induction motor.

Torques in terms of full load:—

	Metal wedges	Fibre wedges
Pull-out	3.50	4.10
Starting	1.70	2.30

points. When used they become practically a part of the core so far as maintenance and operation of the motor are concerned, but are readily removable when necessary.

EFFECT ON MOTOR PERFORMANCE

The main characteristics in induction motor performance are efficiency, power-factor, torque and heating. Other characteristics are considered only in so far as they affect those mentioned, directly or indirectly. All four are modified by the use of metal wedges through the effect they have on magnetizing current, leakage, reactance and iron loss.

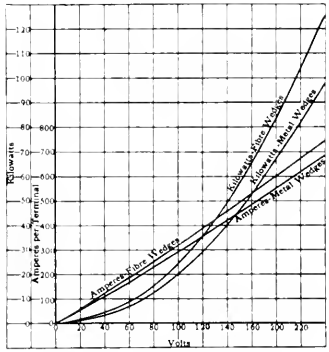

FIG. 6—LOCKED SATURATION CURVE
Same motor as in Fig. 5.

A comparison of test data on the same motor with fibre wedges and with metal wedges is given in Figs. 5, 6 and 7 and Table I. Figs. 8 and 9 show, respectively, a comparison of magnetizing current and iron loss on the same motor, with fibre wedges in one case and with a one-piece metal wedge of cast iron and special metal in the other. Figs. 10 and 11 show a similar comparison on

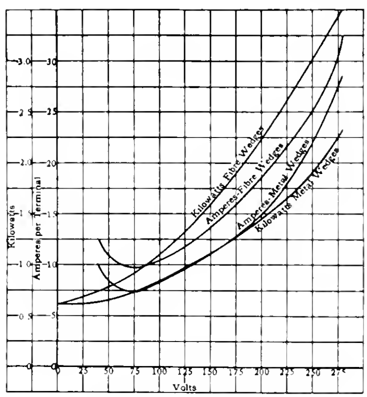

FIG. 7—RUNNING SATURATION CURVES
Same motor as in Fig. 5.

a larger motor. The metal wedges reduce the magnetizing current and iron loss, thereby increasing the power-factor and efficiency, the latter being affected by both reductions. Also there is a slight reduction in both pull-out and starting torque, but not to values that are objectionably low. The torque could be increased again by using less turns in the primary, thereby decreasing

the leakage, and by a little more resistance in the secondary. Since the magnetizing current and core loss are already reduced the margin in power-factor and efficiency is quite large, and these changes can be made without reducing either of these characteristics to an undesirable value.

ANALYSIS OF EFFECT OF MAGNETIC WEDGES ON MOTOR PERFORMANCE

Magnetizing Current—The magnetizing current is dependent upon the winding dimensions, number of

TABLE I—DATA FROM FIGS. 5, 6 AND 7

	Open Slot	Metal Wedged Slot.
Magnetizing Amperes per Terminal	20.8	17.1
Iron Loss (Watts)	1779	913
Locked Amperes	742	684
Locked Watts	126	98
Reactance in Ohms per Phase	0.154	0.171
Full-Load Power-Factor	95.2	96
Full-Load Efficiency	87.5	90.8
Pull-Out Torque	4.1 × F.L.T.	3.56 × F.L.T.
Starting Torque	2.36 × F.L.T.	1.76 × F.L.T.

poles and ampere-turns. However, other things remaining equal, the magnetizing current varies directly as the ampere-turns necessary to produce the required flux. Of the total ampere-turns of the motor, that component which represents the ampere-turns necessary to force the flux across the air-gap usually composes the major portion, and also is the only one which is affected by a change in slot wedges. All of the component items vary directly as the length of the path that the flux must follow, and for the item of air-gap ampere-turns this path is the effective air-gap. The effective air-gap is

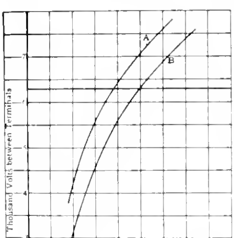

FIG. 8—MAGNETIZING CURRENT

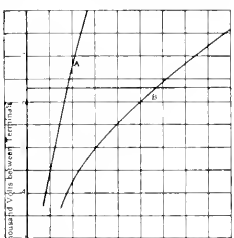

FIG. 9—CORE LOSS

Test results on 450 hp, three-phase, 25 cycle, 6300 volt, 720 r.p.m. induction motor.
A—Magnetic slot wedge (cast-iron and special metal).
B—Fibre slot wedge.

dependent upon the actual air-gap and the gap factor. The latter is composed of two parts, that due to the secondary slot opening and that due to the primary slot opening. With the same secondary slot, the gap factor will then be dependent only on the nature of the primary slot. The gap factor for either primary or secondary is figured from the actual air-gap, the slot pitch and the slot opening in accordance with a modification of Carter's* fringing factor formula. The gap factor varies with these items in such a way that the slot with the largest opening at the air-gap has the largest gap factor, that is, it is in effect the same as having a larger air gap.

In Figs. 1, 3 and 4 assume the same number of slots and same air-gap, and let s represent slot pitch, b slot opening and g air-gap. The major dimensions of the slots in the three figures are the same, namely, $A = 0.3$, $B = 1.5$, $s = 0.8$, $g = 0.05$, $h = 0.125$. Let $b = 0.184$ for Fig. 1, 0.3 for Fig. 3, and 0.125 for Fig. 4. Then for the three cases the gap factors are,—for Fig. 1, 1.11; for Fig. 3, 1.255, and for Fig. 4, 1.053. The value of $b = (A-d)$ from experience and test results. The steel portions of the wedge seems to be only half as effective as would be expected at first glance. This is due to the fact that the steel wedge is not as efficient as a tooth tip which is punched as a part of the tooth, because considerable magnetic reluctance is introduced by the paper insulation between the steel wedge and the tooth proper. The results above obtained indicate that the gap factor for the metal wedge slot will be less than for the open slot, but not quite as small as for the partially closed slot.

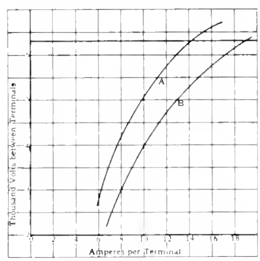

FIG. 10—MAGNETIZING CURRENT

750 hp, three-phase, 25 cycle, 6300 volt, 720 r.p.m. induction motor.
A—Magnetic slot wedge (cast-iron and special metal).
B—Fibre slot wedge.

The values of the magnetizing currents in the three cases will be in the same order. This explains the lower magnetizing current for metal wedges as against fibre wedges in Figs. 7, 8 and 10. Also the higher power-factor means a lower full-load current and less primary copper loss, which helps towards higher efficiency.

Iron Loss—The iron loss is composed of primary tooth loss, loss in the primary core, and loss in the surface of the rotor. The dimensions of core and teeth being the same, the first two items will not be appreciably affected by the nature of the slot opening. The last item, however, is affected considerably by the slot opening. The flux in passing out of the teeth at the air-gap tends to form in tufts at the tooth tips, giving a higher density over the surface of the tooth than in the space opposite the slot opening. This produces variations or pulsations in flux at a frequency corresponding to the number of slots in the primary, which appear as a wave of high frequency superimposed on the fundamental

*See the *Electrical World and Engineer*, Oct. 30, 1901.

wave of the rotating field of the motor, as shown in Fig. 12. This wave is an even harmonic of varying amplitude, apparently composed of two odd harmonics. A beating action is produced and the high-frequency wave will reverse every half cycle of the fundamental flux wave. These high-frequency flux pulsations tend to create losses in the rotor surface, for they result in rapid magnetizing and demagnetizing of the iron of the rotor. This results in hysteresis loss of a considerable amount, since the hysteresis loop is displaced from its normal axis.* Furthermore, the increased frequency and amplitude of the pulsations result in higher losses. This frequency will be the same for the three types of construction when the number of slots is the same. The amplitude, however, will be different, as will be explained later. The fringing of the flux tends to smooth out these variations or decrease the amplitude, but the fringing has less effect with a greater slot opening and has no effect on the frequency. With the same number of slots and the same slot width for the various slots represented in Figs. 1 to 4 the flux densities over the tooth surface will be different. With the dimensions assumed above for these slots, the tooth width at the surface of the primary is,—for Fig. 1, $0.8 - 0.184 = 0.616$; for Fig. 3, $0.8 -$

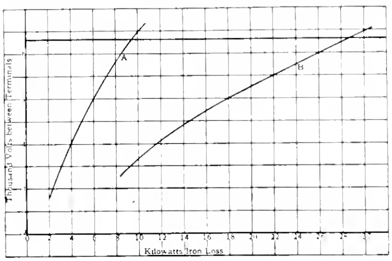

FIG. 11—CORE LOSS

750 hp, three-phase, 25 cycle, 6300 volt, 750 r.p.m. induction motor.

A—Magnetic slot wedge (cast-iron and special metal).
B—Fibre slot wedge.

$0.3 = 0.5$, and for Fig. 4, $0.8 - 0.125 = 0.675$. The flux density in the tooth face will therefore be greater for the open slot than for either the metal wedge slot or partially closed slot. Taking this, together with the fact that the fringing is not as effective to smooth out the variations in flux on the open slot as on the other two types, it is evident that the variations in flux density are greater, and consequently the surface loss is higher, with the open slot. In other words, the action of the metal wedge (and the tooth tip on the partially closed slot) is to make the flux distribution in the air-gap more uniform than is the case with the open slot and, since the pulsations are not as great, the surface iron loss produced is less. The partially closed slot, of course, shows a greater reduction in iron loss than the metal wedge slot. All of which accounts for the test results in Figs. 7, 9 and 11, showing considerably more iron loss for the open slot than for the metal wedged slot.

*See paper by Messrs. Chubb and Spooner in the *Proceedings of the A.I.E.E.*, Oct., 1915.

Leakage Flux—The third and last item to consider is the effect on the leakage flux, which is composed of five parts, namely, that around the primary slot, the secondary slot, the primary end connections, the secondary end connections and that between primary and secondary—known as zigzag leakage. In the case of wound secondaries there is a sixth part known as belt leakage, but this is usually inconsiderable and will not be considered here, as it is not dependent upon the primary slot construction. The latter fact is also true of the secondary slot, and the primary and secondary end connection leakage which eliminates them from consideration, leaving only the primary slot and zigzag leakages to be considered.

The Primary Slot Leakage is directly proportional to the slot factor (among other items), but these other items will be the same, assuming the electrical and mechanical dimensions of the motor to be the same. The slot factor, however, will be different for different slot constructions, but is independent of the other dimensions of the machine. Therefore, other conditions remaining the same, the relations of the slot factors to each other for the various slot constructions will show the relation of the primary slot leakages to each other.

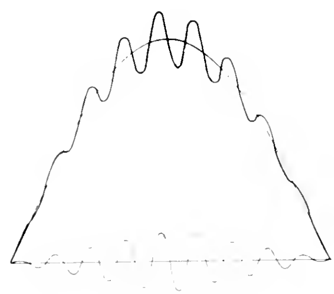

FIG. 12—EFFECT OF HIGH-FREQUENCY FLUX PULSATIONS ON FUNDAMENTAL WAVE

It is known from experience with the type of wedge shown in Fig. 1 that the slot factor for the portion of the slot to the bottom of the wedge is 0.937 for $A = 0.3$.

That due to insulation at d_1 and d_2 is three-eighths of the total insulation divided by the slot width $= 0.066 \div 0.3 = 0.222$, assuming the total insulation depth $= 0.176$ inch. This portion due to slot insulation is figured in this way, because the flux at the two sections of insulation at the center of the slot is only cutting one-half of the conductors that it would cut if it was at the top of the slot and the flux density is only one-half of that at the top of the slot. There is one-quarter of the insulation at the top and one-half at the center of the slot, the portion at the center being only one-quarter as effective for leakage, as stated above, as it would be at the top, so the result is three-eighths of the effect that would obtain if all the insulation was at the top of the slot. In this it is assumed that the insulation at the top of the slot is one-quarter of the total insulation, which is theoretically correct, although prac-

tically there is a little more due to the lapping of the slot cells at the top.

That due to the copper is, of course, the total copper depth divided by three times the slot width $= 1.199 \div 0.9 = 1.34$. Therefore, the total slot factor $= 0.937 + 0.220 + 1.34 = 2.497$.

For Fig. 3 the factor for the portion of the slot to the top of the coil insulation will be the depth to the top of the coil divided by the slot width $= 0.125 \div 0.3 = 0.417$.

That for the insulation and copper will be the same as for Fig. 1. Therefore, the total slot factor $= 0.417 + 0.220 + 1.34 = 1.977$.

For Fig. 4, although the insulation is usually heavier and the copper space less, these will be assumed the same as the other two, which will not be appreciably in error. Then the slot factor for these two parts will be the same as for the other two slots. That for the part of the slot down to the top of the coil insulation will be the depth to the tapered part of the tooth tip divided by the slot opening, plus the depth of the tapered part of the tooth tip divided by the average of the width of slot and slot opening $= \frac{0.0625}{0.125} + \left\{ \frac{0.0625}{\frac{0.125 + 0.3}{2}} \right\} = 0.5 + 0.294 = 0.794$. Then the total slot factor $= 0.794 + 0.220 + 1.34 = 2.354$.

This shows that, of the three slot constructions considered, that with the metal wedge has the highest slot factor, even higher than the partially closed slot, and consequently it has the greatest primary slot leakage.

Zigzag Leakage—The other portion of the leakage reactance that is affected by the slot construction is the zigzag leakage. There are a number of items upon which it is dependent, but, as before, all of these items but one will be the same for the same mechanical and electrical dimensions of the motor. This other item, namely, the effective air-gap, will be different for the different slot constructions, although the various dimensions of the motor are the same. The zigzag leakage is inversely proportional to the effective air-gap, so the slot construction that gives the largest effective air-gap will have the lowest zigzag leakage.

Referring again to the portion of this article discussing the magnetizing current, it will be noted that the open slot has the largest gap factor, with the metal wedge slot next, and the partially closed slot next in order. The effective air-gap will have the same relation, since the effective air-gap is the product of actual air-gap and the gap factor. Therefore, the open slot will have the smallest zigzag leakage, with the metal wedge slot next and the partially closed slot next in order.

Summing up the total leakage flux, it will be noted that the open slot has the smallest leakage, with the metal wedge slot and the partially closed slot following, the order in this case being doubtful without more detailed calculation. It is known, however, from tests that the partially closed slot has a greater leakage than the metal wedge slot, other things being equal.

Since the metal wedge slot has more leakage flux or reactance than the open slot, it will have greater impedance, the resistance being the same, and consequently less current will flow for a given voltage and less wattage will be obtained. This accounts for the results obtained in curves, Fig. 6 (locked saturation), and indicated in Table I. With less current flowing for a given voltage there will be less torque, as the torque will vary directly as the current. Therefore, the higher leakage flux accounts for the lower torque obtained with the metal wedged slot construction as against the open slot. This is also shown in Table I and in Fig. 5.

CONCLUSION

From the data given and the foregoing discussion it will be seen that, while the metal wedged slot construction does not give as low magnetizing current and iron loss as the partially closed slot, it does give lower values than the open slot. At the same time it maintains the advantages of the open slot in ease of winding and repair. The leakage flux is higher and the torques lower but, with the margin to spare in both magnetizing current and losses as mentioned, it is possible to reduce the number of turns per coil and perhaps increase the size of conductor in the metal wedged slot. By this means it is possible, while maintaining a high power-factor, to obtain still higher efficiency (at higher loads at least) than with the open slot construction. Also, the torque of the open slot construction can probably be equaled. Or, if desired, with the turns per coil the same as on the open slot motor, a larger air-gap can be used with the metal wedged slot construction, maintaining the same power-factor as with the open slot construction and gaining some in efficiency and torque, due respectively to less iron loss and less leakage. The metal wedged slot construction thus gives a certain flexibility in design, so far as performance is concerned, and opens up possibilities for working the active material more efficiently than is possible with the open slot construction, while at the same time all the advantages of the open slot construction are retained.

The Testing of Fan Motors

O. F. Rowe

THE purpose of a fan is to assist in ventilation and, in some cases, to supply the entire ventilation for a room or building. The purchaser is, therefore, directly interested in the air delivery, power consumption, size, weight and life of the working parts. These qualities are largely determined by the design of the motor, but every fan motor should be tested before it leaves the factory to make sure that it meets the requirements as to speed and power consumption, in addition to an endurance run of a few hours. Additional tests are usually made on a few samples to ascertain the exact results secured, and some of these tests will be of interest to fan users.

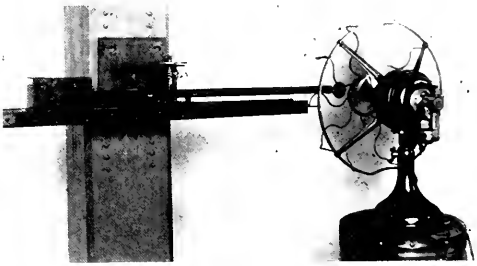

FIG. 1—TARGET ANEMOMETER
Used to measure the velocity of the air as it leaves the fan.

Primarily, the purchaser is interested in the amount of air delivered by the fan, and the power taken by the motor. There are several ways of measuring the air delivery. A rough estimate is sometimes obtained by ascertaining the maximum velocity with a paddle-wheel anemometer or pitot tube, and multiplying this velocity by the area of the fan in square feet. The anemometer indicates the velocity in feet per minute, and multiplying this by the area gives roughly the volume of air displaced per minute. This method is far from accurate, however, due to the peculiar shape of the air-velocity curve, as shown in Fig. 2. The maximum velocity is really active over only a small portion of the total area of the fan, and that to multiply this value by the total area would give a volume far in excess of the true value. Due to this sharp velocity peak, it is necessary to measure the velocity with either a pitot tube or some similar device, the paddle-wheel anemometer being entirely too large, and giving only an average of the actual values desired. The values shown by the curve, Fig. 2, were obtained by use of the target anemometer. This instrument, shown in Fig. 1, consists of a small target approximately one inch in diameter, on the end of a light aluminum arm. The arm is fastened at the middle to a shaft, carrying a precision meter spring and a graduated dial. The end of the arm opposite the target carries several vanes in a dash-pot to damp the vibrations and a pointer which indicates the zero position. Readings are taken by balancing the torque of the meter spring against the thrust of the air on the target, and reading the degrees deflection on the dial. The instrument was calibrated with a standard paddle-wheel anemometer.

The correct volume of air was obtained by taking the readings, as shown in Fig. 3, six inches in front of the fan, so that only the air which passed through the blades was measured, and by excluding the entrained air no fictitious result was obtained. The small cross-marks on the diagram show the readings taken every inch, and in all four quadrants, from the center line of the fan to the outside circle. Readings were taken in the four directions to secure a more accurate result and to eliminate the effect of the "shadow" of the base of the motor in the air column. The average of the four readings on each concentric circle is used as the average velocity of the area between the two concentric circles midway between the adjacent velocity circles. For example:—The velocity at zero is the average velocity for the circle *a*; the velocity at *1* is the average velocity for the area between circles *a* and *b*; the velocity at *2* is the average for the areas *b* and *c*, etc. The areas involved and the total volume, as computed from Fig. 1, are given in Table I. The closer together the points were taken on the curve in Fig. 1 the more accurate were the results obtained. The difference between this method and the product of the maximum velocity and the total area are very evident. The correct volume is 1740 cu. ft. per minute, while the maximum velocity of 2000 ft. per minute times the total area of 1.366 sq. ft. gives 2792 cu. ft. per minute, or an error of 1050 cu. ft. per minute.

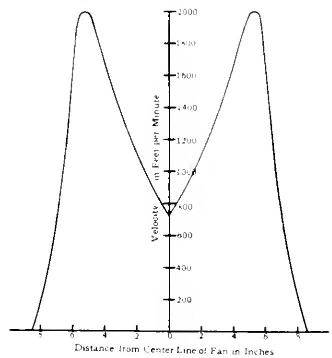

FIG. 2—AIR-VELOCITY CURVE
Obtained by use of the target anemometer.

These refinements are not so necessary for ceiling fans, where the areas involved are much larger and a

paddle-wheel anemometer can be used very satisfactorily. The paddle-wheel anemometer is also useful in calculating the distance to which a fan will blow the air and the width of the air column. The most desirable fan is one which will not only penetrate to the greatest distance, but will also cover the greatest area. A typical air-column curve is shown in Fig. 4.

TABLE I—VOLUME CALCULATION

Area		Average Velocity Ft. per Min.	Volume in cu. ft.
Position on diag.	sq. ft.		
a	0 0053	730	4
a—**b**	0 0437	897	39
b—*c*	0 0874	1240	108
c—**d**	0 1310	1390	182
d—*e*	0 1750	1610	282
e—*f*	0 2183	1970	431
f—*g*	0 2620	1570	412
g—*h*	0 3050	720	219
h—*i*	0 3490	180	63
		Total	1740

The true measure of the efficiency of a fan motor, so far as the user is concerned, is the number of cubic feet of air moved per watt input to the motor, the input being measured by an ordinary wattmeter. The efficiency of the motor itself and the torque transmitted to the blade are not easy to measure. The air moved by the fan has a very decided cooling effect on the motor, and a brake test does not always give accurate results, due to the changes in the temperature. For this purpose an adaptation of the cradle dynamometer has been devised, a view of which in actual operation is shown in Fig. 5. The motor is set on a platform, which is adjusted so that the center line of the shaft passes through the center line of the clock springs *aa*, used in place of knife edges

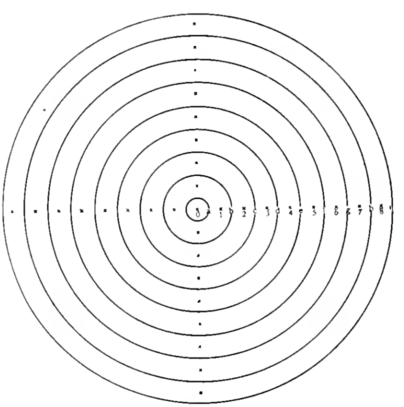

FIG. 3—DIAGRAM USED TO DETERMINE THE VOLUME OF AIR WHICH PASSED THROUGH THE BLADES

to support the moving framework carrying the motor and fan. The center of gravity of the moving framework and motor is then adjusted by means of the weight *w*, so that it is very slightly under the points of suspension, and will cause the framework to return to its initial position when the fan is not running. The reaction of the blade against the air is transmitted through the motor to the pivoted framework and is balanced by a sliding weight on a graduated scale *b*. A pointer *c* and a releasing mechanism *d* enable the operator to adjust the sliding weight, until the pointer *c* remains in the zero position. The ounce-inches torque are then read directly from the scale. The speed of the motor is measured by the use of a watthour meter dial (not shown) and a stop watch. The following formulae give the output and efficiency when the torque and r.p.m. are known:—

$$\textit{Watts Output} = \frac{\textit{R.p.m.} \times \textit{oz.-in. (Torque)}}{1350} \qquad \textit{Efficiency} = \frac{\textit{Watts Output}}{\textit{Watts Input}}$$

The use of a meter dial for measuring the speed has been found to be very satisfactory, as it takes very little power compared with the ordinary speed indicator, and therefore does not interfere with the accuracy of the data.

One of the commercial checks on output which is easily made is to place two similar fans one or two feet

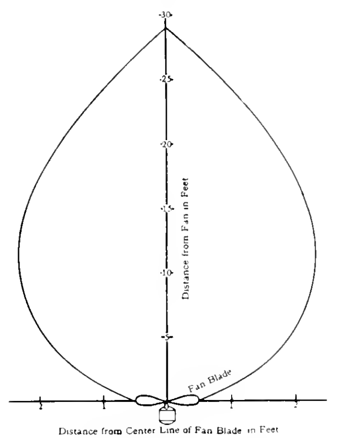

FIG. 4—TYPICAL AIR-COLUMN CURVE OF TWELVE-INCH FAN

apart, facing each other. A point is then found between them where a large sheet of cardboard or other light material comes to rest. The distance between the fan blades and the cardboard is a rough check upon the two air deliveries.* To check the true efficiency, the watts input to each motor must be taken into account.

The wearing parts of fan motors are carefully tested. One of the chief objections to a series or shunt motor is the wearing of the brushes and commutator. A good brush should have long life, but should not wear the commutator. It has been found possible to secure a brush life of from 5000 to 30 000 hours, depending on the type of the motor, with no apparent wear on the commutator. In this connection it should be noted that incorrect results are sometimes obtained by making a short run of 200 to 300 hours, and assuming that the

*See also an article on "The Selection of an Electric Fan," by Mr. H. M. Scheibe, in the JOURNAL for August, 1912, p. 715.

entire life of the brush will be proportional. This is not true, as some brushes will be found to wear faster as the commutator becomes worn and dirty. To secure correct results it is necessary to make an endurance run for the entire length of time.

A large percentage of fan motors go into the hands of users who know little of the care that should be given them to secure the best operation. Instruction tags are easily lost or destroyed, and it is therefore necessary to equip motors with a lubrication system that will last as long as possible with a minimum amount of attention. Refinements in design have made it possible to reduce the size and weight of the rotating parts, and the bearings of drawn steel motors can therefore be made considerably smaller than on older types without interfering with the life of the bearing. Tests on standard bearings show that the life of a phosphor-bronze bearing with a hardened steel shaft may vary from 20 000 to 30 000 hours with a good lubricating system, and even longer under good working conditions. To secure reliable bearing tests it is preferable to give the motors a continuous run of from 5000 to 10 000 hours under actual working conditions. Even then the amount of wear on good bearings is so small that it can only be measured by an expert.

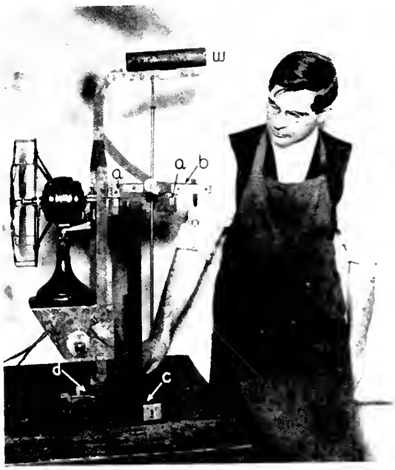

FIG. 5—MODIFIED CRADLE DYNAMOMETER
aa—Center line of shaft and pivot points. *b*—Graduated scale. *c*—Pointer. *d*—Releasing mechanism. *w*—Weight.

On oscillating fan motors the cable which connects the motor body to the base should be carefully tested. The continuous bending of this cable, due to the movement of the motor body, seriously affects its life. In Fig. 6 is shown a device which has been used to test various kinds of cable for bending, giving as nearly as possible the conditions met with on the motor, but at a much faster rate. It consists of a disc of wood mounted on the end of a motor shaft and caused to rotate at about 175 r.p.m. The disc carries a swivel connection, *a*, to which the middle of the cord to be tested is fastened, the two ends of the cord being fastened to the frame work as shown. The motor is connected in series with the cable, so that a break in the cable will cause the motor, and therefore counter *b*, to stop. Every revolution of the disc gives the cable a complete bend, and the counter can therefore be made to register the total number of bends. A good cable should stand as high as seven to eight million bends before breaking. An oscillator, making a complete oscillation eight times a minute, would therefore run about two years on one piece of cable, assuming that it ran day and night for 265 days. It is safe to say that the ordinary motor runs only one-quarter of this time at the most, and has accordingly a cable life of at least eight years. It is evident that any sharp bend in the cable would shorten its life, and care should be taken to handle it with as much care as possible.

Many induction motors use a centrifugal switch to open the starting winding circuit when the motor comes up to speed. Unless carefully designed, this switch is apt to cause trouble, and it should accordingly be given a thorough test. This is done by means of a contact mechanism which supplies the motor with current for a time long enough to enable it to start and then breaks the circuit and holds it open until it has had a chance to stop. A counter connected to a solenoid in series with the motor records the number of starts, and an overload time relay can be used to open the circuit when the switch breaks down and the motor fails to start. A good switch lasts for about 200 000 starts. Counting 2000 starts a year, which is an average of over five a day, the life of the switch is about 100 years. The use of a switch of this character makes it possible to greatly increase the efficiency of single-phase motors, because the starting winding can be removed from the line when not used.

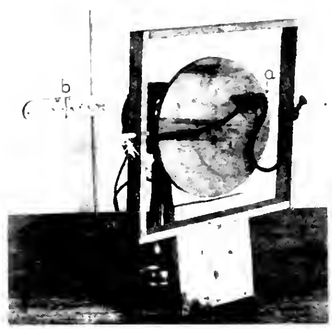

FIG. 6—CABLE-TESTING DEVICE

Some of these tests must be made in the laboratory, but the simpler ones enable the dealer and the customer to select the best from the various designs on the market, bearing in mind that the most efficient fan is the one which gives the greatest air delivery for the smallest amount of power; size, weight and appearance being also considered.

Maintaining and Fostering Public Utility Development Under Regulation

Edwin D. Dreyfus

THE introduction of public utility regulation should always be undertaken with the view of a gradual adjustment to the new conditions and standards rather than as an attempt at any abrupt enforcement of conformity to later-day conceptions. To do otherwise would result in undermining the stability and growth of our public utilities, thus establishing a setback, with resulting inconvenience and corresponding loss to the public.

It is quite difficult to lay down in general terms corrective measures that will apply to all conditions encountered, but we may well take notice of the course of certain events since the new order of regulation was inaugurated about nine years ago. Essentially the big factor that stands out prominently in this whole question of regulation is the matter of public opinion and confidence. This requires little, if any, emphasis. It is the general attitude of the public towards the utilities that is finally reflected in the character of regulation administered by any division of the government. The power of public opinion in a democratic government is fundamentally controlling and, while it may be temporarily upset in traveling the usual course of governmental machinery, nevertheless, it ultimately prevails. It is to the people direct that the utility should primarily address itself, and it should not, as often is the case, rely too greatly upon the actions of representatives of the people who may attempt to give their interpretation of the will of the people. Sometimes they do this as they should, and again they are moved to prejudicial actions in the hopes of gaining public favor, not infrequently at heavy cost to the utilities companies.

The steam railroads have set the example in enlisting public support through their broad campaigns made to obtain fair consideration in their rate cases, and furthermore, to secure sane legislation in some states which either had obstructive laws in force or in contemplation. A full and candid discussion of the needs of the public utility and a true disclosure of their economic position should develop a sympathetic interest on the part of the thinking public.

It is practically an established fact that people as a rule believe in fair play, and if they may be brought to a clear understanding of the situations that have surrounded the growth of public utilities they will be inclined to accede a liberal interpretation of all reasonable means which were employed in developing the utilities, and will not be disposed to allow the placing of undue restrictions against the extension of such properties.

Admittedly, the attainment of this end is not to be looked for until an earnest and united effort is made by the utilities to accomplish such desideratum, and due time is allowed for the disseminated knowledge of the public utility business to percolate through the masses of the people. As the utility business is of an intricate nature, the task of bringing to the public an adequate realization of the conditions that induce the most profitable development for both rate-payer and investor is evidently not simple, but the eventual benefit to be thus achieved, as outlined later, cannot well be controverted.

When the public service commissions first began their work the public utilities generally were naturally cautious in the divulging of what had hitherto been considered confidential information. The public utility act empowers the commission to order any and all information required for the proper regulation of the utilities, but very few of the state commissions have abused their inquisitorial powers and nearly all have, furthermore, measured their course slowly and wisely because of the vast data that would accumulate which could not be satisfactorily utilized unless a large engineering and clerical force was maintained. In view of this slowness, some companies continued the "laissez faire" policy and did not proceed on their own initiative to review historically the different stages of their corporate development in order to establish the real investment made (to be supported by an appraisal if the construction records are incomplete) and to analyze the cost of the different services rendered which would make their rates productive of the largest business expansion without being exorbitant for any one class, or without producing adequate returns from another.

If a company neglects to submit its affairs to a thorough inspection of its own officials and defers doing so until a day of reckoning is brought on through lack of confidence and dissatisfaction by the consuming public, then the company must petition for a delay until it may gather data. There can be but one result,—the arguments and data that the respondent may file will be labeled as "prepared for the occasion" and thereby likely to be considered as influenced by necessity. The affairs of the company will then be examined more circumspectly and, with confidence shattered, they may no longer expect to receive the benefit of any doubt that might other-

wise have been granted them. It becomes a compromise, with the company obliged to yield practically every claim on points of valuation and earnings up to the limit of confiscation, when it may seek protection under the fourteenth amendment to the United States Constitution, which prevents the confiscation of investment in property without due process of law. But to resort to the courts is a costly proceeding. The expense of a long-drawn-out commission hearing and, in all probability, later reviews by the courts, would be manifold as compared with the cost of making this preparation a part of the ordinary business procedure.

It only requires a little reading of the testimony in some of the various rate cases coming before the commissions to impress one with the woeful lack of preparedness and, in spite of all the expert talent the companies called to their aid, the "die was cast" and the amount of valuations and earnings suffered a drastic scaling down. It is possible in some cases that the earnings would have been found excessive, viewed from the standpoint of monopoly, even when based upon the valuation carried upon the company's books at the time of the investigation. Then the position of the company would certainly be prejudiced and impaired by not having voluntarily undertaken to adjust its own rates according to the letter and spirit of the law. But the situation will be far worse in such cases where the company is unable to even support its valuation by any tangible records, or readily substantiate its investments by a careful exposition of the different stages of development of the company and the expenditures entailed in each period. Naturally the general objection to the plan of due preparation lies in the cost of appraisals and other examinations usually required. Exhaustive appraisals, wherein every conceivable item and operation involved in constructing the existing plant is separately enumerated and evaluated, call for appropriations of serious sums of money. Composite appraisals, in which quite general divisions only are considered and average costs applied (having been selected with proper regard to the constituent details), on the other hand, may be made at reasonable costs. The latter should prove ample for all business needs and also serve the purposes of regulation. The appraisal of the physical plant is only a guide or stepping stone in determining the final fair value, as in effect enunciated in the celebrated *Smyth vs. Ames* case,* and as public service commissioners will hold after having acquired a comprehensive understanding of the public utility situation and development. Companies who are capable financially may, at their own discretion, undertake their valuations with great refinement in quest of further instructive information. If a company has no detailed data as to the distribution of its investment, the following advantages are to be gained through a complete valuation of the property:—

a—Establishing the equity back of the investment.

b—Providing a definite basis for measuring the rate of return.

c—Making reasonable apportionments of the investment as devoted to the different classes of service rendered.

d—Affording a reclassification of the elements of the property to correspond with an established uniform system of accounting.

e—Furnishing a basis of sale or transfer of the property in either public or private sale, or for mergers and consolidations.

f—Enabling the company and the municipality to appropriately fit terms on renewal of franchises or in the readjustment of ordinance rates.

g—Securing the required information where taxes are founded upon inventories.

h—Deriving values to be applied to such parts of the property upon which insurance should be carried.

i In indicating the probable needs of the business.

Apart from all other considerations, the wisdom of placing the utility business in true alignment with the requirements contemplated by modern regulatory laws is constantly becoming more apparent. If a company remains inactive in this respect, the possible consequences are that the regulatory body may institute a disciplinary order admitting competition, or else may be rigid in its interpretation of the theories of regulation. In either case the company may be left in an awkward position. These developments are no longer subjects of conjecture, but are now matters of record. The first signal case to be mentioned is that of the Railroad Commission of California in its decision in Case No. 260, *Pacific Gas & Electric Company vs. Great Western Power Company*, decided June 16, 1912, in which the Pacific Gas & Electric Company protested the application of the Great Western Power Company for a certificate of convenience and necessity to enter certain territory already occupied by the Pacific Gas & Electric Company. The commission reviewed the situation in much detail, showing where the company had been at fault, evinced what it thought the interest of the public was, and finally permitted competition. In part, the commission stated that,—

"The application of the Great Western Power Company * * * is granted for the reason that we find the service of the Pacific Gas & Electric Company therein is neither complete nor adequate, and the rates charged therein, except under stress of competition, have been higher than should have been maintained."

Continuing on the above principle, the commission asserted,—

"Likewise it appears that although the Pacific Gas & Electric Company is now willing to put in the lower rates which have been offered by the Great Western Power Company, it did not show any such inclination until the Great Western Power Company had tendered the lower rates. * * * We feel that it is our duty to the public in the congested sections covered by the application of the Great Western Power Company to permit the second utility to come in, even if in doing so it shall take away a portion of the business now being held by the Pacific Gas & Electric Company."

*"We hold, however, that the basis of all calculations as to the reasonableness of rates to be charged by a corporation maintaining a highway under legislative sanction must be the fair value of the property being used by it for the convenience of the public. And in order to ascertain that value, the original cost of construction, the amount expended in permanent improvements, the amount and market value of its bonds and stock, the present as compared with the original cost of construction, the probable earning capacity of the property under particular rates prescribed by statute, and the sum required to meet operating expenses, are all matters for consideration and are to be given such weight as may be just and right in each case." *Smyth vs. Ames*, 169 U. S., 466.

In addressing the Mayors' Conference held in Philadelphia during the latter part of 1914, Lieutenant Governor Eshleman, of California, formerly chairman of the Railroad Commission of that state, made reference to the case just cited and remarked that the Pacific Gas & Electric Company acknowledged the lesson set down in this decision and accordingly, on its own initiative, adjusted the rates throughout its entire system along the lines covered by the decision. It is equally important that each utility realign its affairs, if circumstances may suggest it, regardless of the state within which the utility may be located. It will in this way fortify its position. The weight of this discussion plainly centers about this very point of preparation, and if the situation, after all factors have been considered, warrants it, then a voluntary readjustment of its rates of service should be undertaken. This would, in all likelihood, be followed by a beneficial expansion of business.

It is not to be argued that the above case is and will remain an isolated one. In fact, it has already established itself as a precedent, and we find the Idaho Public Utilities Commission, approximately three years later, following in no uncertain way the above example of the California Commission,* and likewise admitting competition.

It is well to make reference here to some of the decisions of the California Commission where they have taken more liberal views than shown in the first case mentioned. In the application of the Oro Electric Corporation for permission to engage in business in the city of Stockton,† the commission was of the opinion that the existing utility had not done its duty toward the public by furnishing adequate service at reasonable rates, but notwithstanding this fact the commission gave the utility company the opportunity to adjust matters.

In accepting a franchise to occupy the streets, alleys, lanes, etc., in a municipality the utility assumes a definite duty, and any disregard of its responsibility should, in all fairness to the citizens of the municipality, be subject to corrective measures, either through abrogation of its franchise, which would manifestly be the most drastic step which could be taken, or by the admission of competing utilities in the field, providing, of course, that the most rational means of securing improvement of the service, say through the offices of the utility commission, had first failed.

A company temporarily embarassed or in transient difficulty through unforeseen happenings would hardly be harassed. But if the unsatisfactory state ensuing is allowed to prevail for any length of time, and therefore permitted to become a rather chronic weakness, then the company is no longer entitled to the consideration that would otherwise be its due if energetic and well-directed efforts were made to restore the quality of service.

*In rendering a decision January 16, 1915, in rehearing of the *Great Shoshone & Twin Falls Water Power Company vs. Idaho Power & Light Company*.

†Decided April 20, 1913, Vol. 2, R.C.Ca., 748.

It is of much importance to all utility companies to keep in touch with the latest improvements which could be introduced not only to enable them to determine whether such improvements should be employed by them, but also to be able to answer statements of proposed opposition companies that the operation of such improved devices would enable them to furnish service at a much lower rate in case such statements were made to a public service commission as a means of securing permission to enter a field thus already occupied.

As already observed, the commissions may issue a disciplinary order in some cases by admitting competition, and in others by reducing the valuation and earnings of the utility. Examples of the latter are to be found in the rate cases of two metropolitan cities and a moderate size town. It is interesting to note the values claimed by the companies and those finally allowed by the commission:—

	Value claimed by the company	Value fixed by the commission
St. Louis, Mo.	$24 072 502	$16 134 303
Buffalo, N. Y.	6 166 140	3 194 159
Springfield, Mo.	464 327	300 000

There are, of course, many conditions that surround the values just given, but the amounts as compared glaringly display the outcome of regulation more or less "ideally" applied. It is not to be understood necessarily that the values determined by commissions in all cases were entirely the results of academic consideration of the cost of replacing the property in its present state of development. It is found quite frequently that ample allowances may have been made in the matter of unit costs and indirect construction and overhead expenses in determining the total value of the physical plant. However, in spite of liberal estimates on all existing property, the total value reached may fall below the sum of money actually devoted to the property by the present owners of the stocks and securities of the company, due to the developmental conditions that existed. In such events the investments thought to be legitimately and safely made become invalidated through governmental regulation. If the business has been conducted in restraint of trade, or the methods in vogue prior to utility regulation were opposed to public policy, then the inherent regulatory powers of the state or federal government should be applied. However, the application of the so-called police powers, under which function of government the regulation of public service companies comes, should be approached with due regard to all factors that were instrumental in bringing this great utility business to its present remarkable stage of development.

It may be true that the time has been ripe within recent years to establish new standards for public service companies, but it certainly does not follow that all rules and practices now fixed upon for future guidance should become retroactive, any more than it would be considered equitable in the passage of any other law to attempt to adjust in any way the results of business

legitimately conducted under previous laws, excepting, of course, where palpable abuses existed.

The one phase in the regulation of public service companies which has opened up so much room for argument has been the question of "upon what value should the company be allowed to earn a fair return?" From a purely scientific standpoint the problem of determining the amount of money actually required to reproduce the property used and useful for public convenience at the present time is now fairly well understood. Also the additional considerations such as given in the *Smyth vs. Ames* case. But the final issue, which should be squarely faced by the partisans of both the public and utility interests, rests upon the perplexing question as to whether capital would have been induced to flow into the channels of the public utility enterprises if the returns for the risks undertaken had either been narrowly limited or eliminated entirely during the development stages of the business. With all fair-mindedness it may be said that in all likelihood the utilities would have been restricted to exceedingly limited size and activity if those who possessed the ability, enterprise and courage required had not been allowed to contemplate due profits as compensation for risks assumed in the early days of the business.

What is a more convincing illustration of the risks involved than the case of an artificial gas company whose entire investment becomes jeapordized through the sudden discovery of large natural gas fields within reasonable radius which may be controlled by interests seeking to compete? A water power company may likewise cause the investment in a local steam power plant to suffer. The jitney bus had a demoralizing effect upon some of the street railway companies. A long series of other distracting conditions, both present and past, could be instanced. What the future holds forth is pure speculation, and our regulatory bodies cannot draw too close a line in restricting profits, inasmuch as no guarantee is given against possible losses.

Consolidations and expansions of our different utilities have brought about substantial economies in operation in which the public has materially shared. These results have been secured through the abandonment of perfectly good but small and uneconomical equipment and substituting larger and more efficient apparatus and systems.

That the utilities have required large sums of money for their development is shown by the last report of the Bureau of Census, Department of Commerce, for 1912. The capitalization of the privately-owned central station light and power companies alone represents $2 099 000 000, and has been doubling every five years. In the case of other utilities, exclusive of steam railroads, the sum exceeds 10 billions, and including the steam roads stretches beyond 25 billions. Compared with the total national wealth, which the Census Bureau estimated at $187 739 000 000 for 1912, the position of our utilities stands out prominently. Real property, or the value of improved lands, was one-half of this total wealth, so that of the remainder the utilities represented over 25 percent. To direct any retarding blow at our public utilities is to hold in check further progress of a significant part of our national enterprises.

It is an unalterable economic law that money will naturally flow to those undertakings which offer the greatest opportunities for profit. This governed investments made in the past, and we cannot honorably disclaim a reasonable protection to investors who provided the capital before the utilities were regulated. The state of Maryland particularly has gone so far as to insert the following stipulation in its public service law:—

"Every such valuation shall be so made and ascertained by the commission that as far as possible it shall not disturb the value of bonds of any said corporation issued prior to this Act."

While contending for the rights of the investors with respect to past investments, it would be the height of folly to hold that whatever valuation or capitalization the company may carry on its books should at all times be accepted at face value without adequate proof or other exposition of the propriety of the amounts. The book records of the company may show this sufficiently, but they are often incomplete. Therefore, the company should institute a careful survey of its development to establish the soundness of its capitalization when viewed from the standpoint of our broad economic laws. To be a little more definite, it cannot be overlooked now that a great many properties were purchased by the present owners on the basis of their earning capacity, which rule was usually followed before regulation was enforced. Some commissions have overruled any consideration of the earning capacity as a basis for valuations by stating that it would result in reasoning in a circle. While this attitude may find a place in regulating present earnings it works an injustice when applied to utilities during the time they were promoting the use of their service in competition with other means of lighting and transportation available and convenient for the public.

When the nation, or some subdivision forming a political entity, has sought to promote its industrial and commercial welfare, it has tendered land grants, special privileges and in cases substantial subsidies to private capital to induce the individuals to assume the responsibility of developing the different agencies of transportation, communication and other facilities essential to the progress of its trade, its commerce, its manufacture, its agriculture, and last but not least, its social conditions. While no direct subsidizing was done in the fostering of our various public utilities, with the exception of the railroads, the equivalent condition prevailed in that the authorities and the public acquieseed in the plans upon which the present public service companies were founded. In other words, private interests were allowed a bounty over and above the bare cost of providing the physical property and perfecting the engineering, legal, administrative and operating organizations.

Denying the reasonable claims for this, the intangible capital element, particularly in view of the fact that

it has been covered by large amounts of securities issued in good faith and accordingly purchased by the investing public, would be identical with a case in which the government had furnished an attractive subsidy to a private company to embark upon a certain venture, and after the undertaking had proven financially successful, had turned around and refuted its gift by saying that, as a considerable part of the money was contributed by the people, the company would not be allowed to earn a return upon that portion of the investment. In effect we have a striking parallel in the case of utilities generally where the subsidy took the form of a silent consent to a capitalization upon which they would later be allowed fair returns under evidently reasonable circumstances. Such a procedure provides a stimulus to business promotion similar to that arising through the offering of fixed subsidies in advance.

To the fair-minded there are certain ethics that business must observe with respect to our governmental institutions and policies, and conversely the government should adopt a corresponding ethical course in its treatment of business development. This obviously should be the case where business has not been affected by iniquitous practice, but only by such methods as were required to superinduce a healthy growth. The validity of the argument lies in the fact that the public has benefited and prospered under past conditions. The people do not recognize any responsibility for the failure of any utility undertaking, but on the other hand, will they understandingly and intentionally prevent a compensating reward when by ingenuity, courage and sacrifice a profitable concern has been produced? The main difficulty is that the people do not realize at this time the extent of their obligations to the public service companies, and the task then is to see that the facts in the case are sufficiently understood by the proper expose of the company's financial history. Bring these relevant facts plainly home to the people, as some companies have done—which is only possible by thorough preparation—and a means for relief from undue pressure and agitation will have at least been launched.

Consequently, the utility should, among other things, prepare a synopsis of its history, with a parallel of the probable conditions of development that would have obtained if large amounts of capital had not been attracted to the utility undertakings. Had the original companies remained separate and confined themselves to small districts, it should be prepared to show that the amount of capital invested up to the present time would have been as much, if not more, than resulted through the consolidations that have taken place, although the profits to the promoters in the latter case would be larger than that accruing to the owners of the separate properties. However, the efficiencies which are a direct outcome of consolidation and expansion have brought the charges for the service down to far lower point than would have prevailed with a number of independent companies individually operated and managed.

The public has derived benefits for which, under present political conditions, it is not always willing to recognize its reciprocal duties. Therefore the utilities may hope to win eventually in all of these important matters only through tireless campaigning carried through the different strata of social, political and civic organizations. The accomplishment of this end will depend as much upon the character of the public utility organization itself as upon any one other thing. In no other field of endeavor is there such a necessity for loyalty to the undertaking, and the management in many quarters has responded to this need by organizing various company activities affording social and technical opportunities. But the movement may be profitably carried a step farther in the direction of developing their employes into men of competency, influence and action in whatever sphere they may travel in their respective social positions. In each case they will become the center of reasoning groups of our body politic, in which the tenets and principles of fair treatment for the utilities may be definitely promulgated.

Any implication of novelty in the above proposal would be misleading and erroneous, as in some cases remarkable work has already been done in establishing a friendly spirit, confidence and good will on the part of the public. The national associations have contributed a large share in aid of the cause. However, the brunt of this burden must fall upon the local utilities in the different sections, and upon the alacrity with which they take up these important problems depends their ultimate integrity and their status in the communities in which they operate. The treatment that many companies have received at the hands of various state commissions has made the managements of many utilities sensitive as to any consideration of their valuations until obliged by commission procedure to disclose all the facts. For any utility to set out detailed information indiscriminately, without premeditation and analysis would be likely to be destructive to its best interests, but no arguments may offset the virtual necessity of at least a diagnosis, if not a complete X-ray examination of its own affairs.

Meter Equipment of Outdoor Substations

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AS a result of the great expansion and large adoption of the outdoor substation as a means of distribution, the question of metering the power at these stations has been receiving more and more attention. In the past it has been a very serious problem, but recent developments and simplification of the metering equipment have done away with a good many of the difficulties. The difficulty applied not only to small distributing stations, but to large receiving stations, and to stations which act as a tie-in between two different transmission systems or two separate parts of the same system. With the apparatus which was available until recently it was almost imperative that this metering equipment be placed indoors.

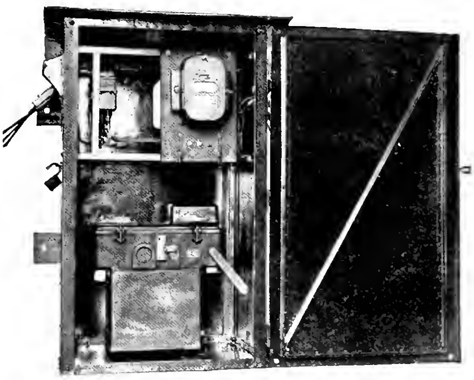

FIG. 1—INTERIOR ARRANGEMENT OF A TYPICAL METER HOUSE

For metering small capacity substations now, the practice is usually to put the equipment on the low-voltage side of the station, running the 2300, 4000 or 6600 volt leads through a special designed metering cabinet. This cabinet contains the series and potential transformers, the wattmeter and usually an automatic oil circuit breaker. If special apparatus, such as curve drawing wattmeters, printometers and time switches, are required, allowances can easily be made for these.

The leads are taken in and out of the box in a very similar manner to that used with distributing transformers. The cabinet can be arranged with a glass window in the door, so that the meter can be read without opening the door. The interior arrangement of a typical metering house is shown in Fig. 1. The line comes in on the left, passes through the series transformers, down through the oil circuit breaker and up on the other side, passing out through bushings of the same type as those through which it came in. Various other types of cabinets are shown in the illustrations, which indicate very distinctly the method of handling the incoming and outgoing lines, and also show the wattmeter through the glass cover on the door.

The potential transformers are tapped to their proper lines through fuses. These fuses should be so located that they are readily accessible for renewal and at the same time are far enough removed so that they offer no menace to inspection. The bottom of the case should be removable, allowing the oil switch tank to be dropped down for inspection. The house can be arranged for mounting on a steel or wood framework and the door locked.

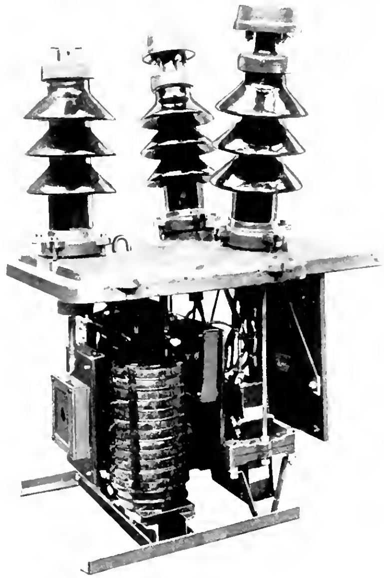

FIG. 2—CURRENT AND VOLTAGE TRANSFORMERS MOUNTED IN ONE CASE

For metering on the high-voltage side of a substation. The tank (not shown) contains two potential and two series transformers, immersed in oil.

Where it is necessary to meter these stations on the high-voltage side, more elaborate apparatus is required. The usual arrangement is that illustrated in Fig. 2, in which two potential and two series transformers are placed in the same tank with oil insulation. The leads are brought in at the top through regular transformer terminals and bushings. The wattmeter is mounted in a receptacle on the side of the apparatus,

where it is thoroughly housed in, and connections can be made to it very readily, as the apparatus is designed for this particular purpose.

This apparatus has worked out very satisfactorily in a good many instances, although it has the defect of having all the eggs in one basket. The clearances between phases should be a minimum to prevent the apparatus from becoming too large and cumbersome.

The design of a steel structure and the arrangement of bus-bars and switching and protective apparatus for any station should be determined by the present and possibly future requirements of the station. Though these requirements often vary widely, the design and building of such stations is no longer considered as special or unusual work.

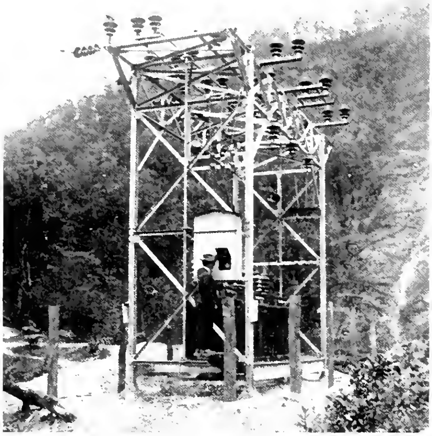

FIG. 3—44 000 VOLT OUTDOOR SUBSTATION
The glass window in the door permits reading the meter without gaining access to the apparatus in the meter box.

SOME TYPICAL EXAMPLES

In Fig. 3 is shown an outdoor substation on the 44 000 volt lines of the Virginia Power Company serving a coal mine load. The horn gap switching and protective apparatus is mounted on the top of the steel structure, and transformers are carried on the platform about two feet above ground level. The secondary bus lines are carried above the transformers and into the metering cabinet, mounted on the end of the structure, and the outgoing lines are connected through hook-type disconnecting switches. This cabinet is arranged with a window through which the meter may be read.

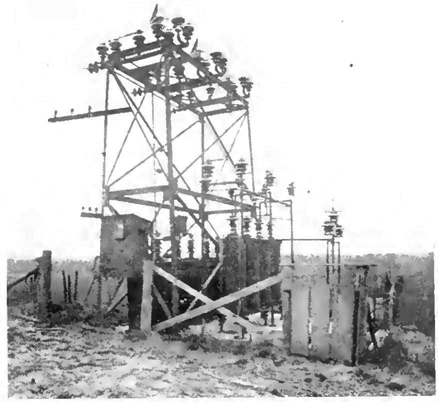

FIG. 4—TYPICAL 44 000 VOLT SUBSTATION

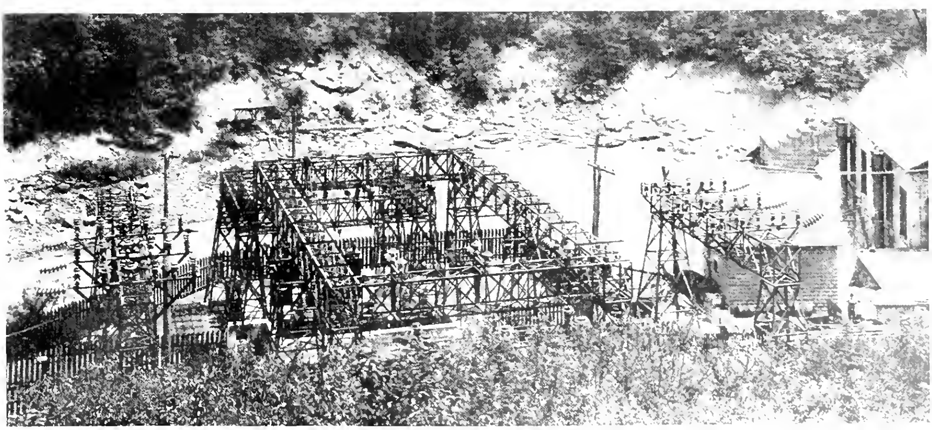

FIG. 5—OUTDOOR TIE-IN SUBSTATION AT ELLWOOD CITY

The substation shown in Fig. 4 is in service on the 44 000 volt lines of the Evansville Public Service Company near Evansville, Ind. The transformers are mounted on a concrete mat under the tower and are protected by horn-gap switches, fuses and an electrolytic

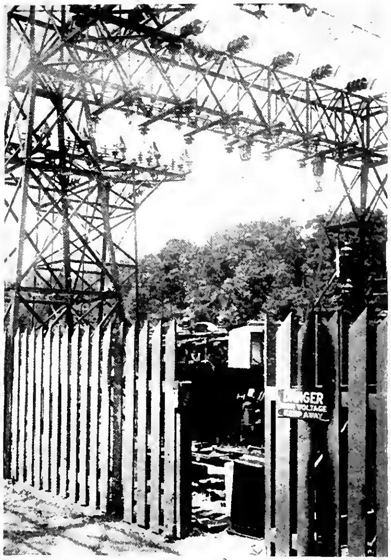

FIG. 6—DETAIL VIEW OF SUBSTATION SHOWN IN FIG. 5
The current transformers are suspended below the upper truss and are connected around a strain insulator, thereby eliminating any mechanical stresses on the terminals.

lightning arrester. The secondary circuit from the transformers is carried through a switch and metering cabinet such as shown in Fig. 1. The simple and compact design of this complete station is typical of a modern outdoor substation.

The large station shown in Fig. 5 is an important link in the system of power distribution, built to meet the increased demands for electrical power in large quantities, which has come with a bounding forward of industrial enterprises in the Mahoning and Shenango valleys. It is installed at the plant of the Pennsylvania Power Company at Ellwood City and ties in with the extensive system of the Mahoning & Shenango Railway & Light Company. All of the equipment at this station, which occupies a space of 150 by 180 feet, is mounted outdoors, and practically all of the apparatus is of standard design. A partial view of this station, Fig. 6, shows suspended-type current transformers for 22 000 volts, which is a detail recently developed.

The evolution of the outdoor substation has proceeded as a direct and natural outcome of the appreciation of the benefits and attractions afforded by the application of electricity to industrial and mining operations. Utility, economy and safety have all combined to bring about the development of the complete and substantial apparatus which can be had for this kind of service.

Speed Regulation of Adjustable Speed Motors

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Electric motor drive has proven so successful in industrial plants that many manufacturers of industrial machinery, especially in the machine tool trade, are regularly incorporating the driving motor as an integral part of the machine. Where direct current is available the shunt motor is well adapted for this service, as the ease with which the speed and direction of rotation may be changed with this type of motor often make it possible to simplify the mechanical construction of the tool to a considerable extent by eliminating change gears or pulleys and belts. At first sight shunt field control seems very simple. Various limitations and complications arise, however, when operating a motor on a weak field which make this condition a problem in itself.

Motors for this service generally have intermittent ratings, and all materials are therefore worked somewhat harder than is the case with continuous rated motors. This makes it possible to obtain a higher rating for the same cost, but at the same time it means that great care must be taken in the design in order to obtain good characteristics.

In any direct-current machine operating under load the cross-magnetization of the armature distorts the main field and shifts the electrical neutral. It is necessary in non-commutating pole machines to shift the brushes to a position which will give good average commutation at all loads. When operating on a very weak field the neutral is shifted so far that it is impossible to find a position for the brushes that will give good commutation over a wide range of load.

The commutating-pole motor offers a logical solution to this problem, for the commutating poles definitely determine the position of the brushes for all loads and speeds. They do not prevent armature reaction, but do keep the neutral stationary and at the mechanical center between poles by the simple expediency of balancing the cross-magnetization at that point. This is of prime importance in any machine used for reversing service, for the brushes must be on the mechanical neutral in order to obtain like speed curves and good commutation for both directions of rotation.

SPEED REGULATION

Adjustable speed motors are almost invariably shunt wound. Only for very special applications are compound-wound machines used, and then the speed range is small.

The speed of any direct-current motor depends upon the impressed e.m.f., the IR drop and the flux. This relation is expressed simply as follows:—

$$R.p.m. = \frac{(E - IR) \times 10^8}{W_s \, p \, \Phi \times 60}$$

Where E = Impressed e.m.f. I = Armature current. R = Resistance of armature, commutating and series coils. W_s = Conductors in series on armature. p = Number of main poles. Φ = Useful flux issuing from one pole.

If it be assumed that the e.m.f. and flux are constant the equation for speeds reduces to $R.p.m. = K (E - IR)$. This is the equation of a straight line and gives a speed curve as shown by Fig. 1.

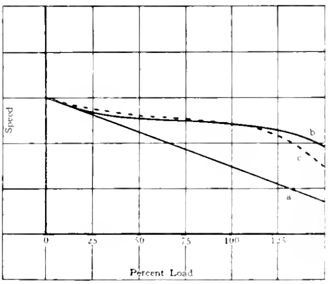

FIG. 1—TYPICAL SPEED REGULATION CURVES

This condition is approached in the shunt motor where the field excitation is kept nearly constant. In practice the flux cannot be kept constant, since it is more or less affected by the armature reaction, by local currents in the armature coil short-circuited by the brush, and by the series coil, if one is present.

EFFECT OF ARMATURE REACTION ON SPEED

Under load, the cross magnetization of the armature distorts the field so that the flux tends to bunch at one pole tip. This saturates the teeth and tip in such a manner that for the same excitation there will be less flux than at no-load. The resulting decrease in flux tends to counteract the effect of the IR drop, and may in some cases cause a rising speed curve. Usually the distortion effect is greater than that of the IR drop, so in order to keep a flat speed curve it becomes necessary to increase the excitation slightly. This is done by the addition of a small series coil known as the compensating coil. This additional winding is not always necessary, especially in small machines, where the IR drop is relatively large. It is rarely possible to obtain a speed curve that is a straight line. Usually there is a sudden drop from no load to about one-quarter load, where it will become constant and remain so up to one and one-quarter load, where it will again drop, as in b, Fig 1. This tendency to drop suddenly at light loads is explained by the fact that there is very little reduction in flux at light load, and thus the drooping effect of the IR drop and the compensating coil predominate. At heavier loads the distortion will very nearly counterbalance the IR drop, thus giving nearly a flat speed curve. For heavy overloads the effect of the distortion again becomes less and the curve will drop.

EFFECT OF LOCAL CURRENT IN THE SHORT-CIRCUITED ARMATURE COIL ON THE SPEED

Great care must be exercised in designing an adjustable speed motor to proportion the commutating poles so that sparkless commutation may be obtained under all conditions of speed and load. In a direct-current motor, good commutation depends upon the limiting of the short-circuit current in the brush. This current is a function of the reactance voltage in the short-circuited coil. In the case of a commutating-pole machine the reactance voltage is very nearly balanced or neutralized by a similar voltage, generated by the coil cutting the commutating-pole flux, which should be of such a value that these voltages just neutralize at all loads and speeds. Since the reactance voltage is a direct function of the armature current, it follows that for exact compensation the commutating-pole flux must increase directly with this current. The commutating-pole excitation is kept in direct proportion by connecting the coils in series with the armature. However, the flux will not increase directly with the excitation on account of saturation in the iron parts of the circuit. Thus the correct amount of flux cannot be obtained for all loads. In a well-designed machine all parts of the commutating-pole circuit are kept as free from saturation as possible so as to limit this condition. Fig. 2 shows the usual relation; the straight line a represents the flux required for exact compensation at the various loads, while curve b shows the actual commutating-pole flux obtained. In order to keep the flux always as nearly as possible at the correct value it is necessary to allow more than is needed at light loads, while at heavy loads there will not be quite enough. This gives an over-compensated condition for light loads, and an under-compensated condition for heavy loads, so that there will always be a certain amount of unneutralized reactance voltage at all loads except at the point where the two curves cross. Fortunately, in a well-designed motor this voltage difference over the required range of load is so small that the high resistance of the carbon brushes will limit the short-circuit current enough to insure good commutation.

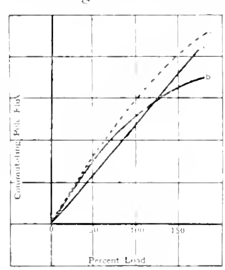

FIG. 2—TYPICAL COMMUTATING-POLE SATURATION CURVES

The conditions as stated above apply directly to both constant-speed motors and adjustable-speed motors at low speed. Another factor enters when an adjustable-speed motor operates on a weak field. At low speed and a strong main field the yoke is saturated more or less, while at the higher speeds and a weak field this

saturation is not present. Since the flux from both the main poles and commutating poles is carried by the yoke, it is evident that any change in one will affect the other. This condition at high speed is expressed by the dotted curve *c*, Fig. 2. Usually the commutating-pole saturation curve will be higher at high speed than at low speed, as shown, although in some cases the reverse is true where there is saturation in the commutating pole itself.

The commutating-pole excitation is constant for the same current regardless of the speed. At high speed the main pole is free from saturation and there is considerable commutating-pole leakage flux. At low speed, and with a highly saturated main pole as part of the leakage circuit, the leakage will be noticeably less. This difference in leakage flux at the various speeds often determines the saturation of the commutating pole. The increased saturation in the commutating pole itself at high speeds may more than offset the decrease in saturation in the yoke.

If the commutating coil be so proportioned as to give a condition of flux suitable for low speed, as in curve *b*, the high-speed relation *c* will give an over-compensation at all loads. Since the reactance voltage is also a direct function of the frequency this over-compensation may cause sparking. This explains why it is not good practice to use motors designed for constant speed, over very wide ranges of adjustment, unless the characteristics are known.

Motors designed for adjustable speed have the commutating coils adjusted so as to give the best compensation at high speed. At lower speeds they will be slightly under-compensated, but usually not enough to affect commutation, on account of the low frequency. It is important that the commutating coil be adjusted as closely as possible, so that there be no more short-circuit current than is absolutely necessary. Even though the commutation may be excellent, the short-circuit current in the armature coils may be sufficient to change the shape of the speed curves at the high speed. The explanation of this is as follows:—

The complete magnetic circuit of a commutating-pole motor is shown in Fig. 3. Consider, first, that the commutating pole is too strong, giving an over-compensated condition, that is, the e.m.f. generated in coil *a* by its cutting the commutating-pole flux is greater than the reactance voltage. This will cause the current to flow around the coil and through the brush, as indicated by the arrows. An inspection of the figure will show that this coil encircles the path of the main flux in the same way as do the shunt and series coils. Thus it will either add to or subtract from the total excitation of the circuit. Over-compensation causes a demagnetization of the field or a differential compounding effect, while the reverse is true for under-compensation. The action of the commutating pole, as explained above, is rarely noticeable at low speed, but may be quite a factor at high speed. The excitation of the armature coil will be present, more or less, at all speeds, but it will not produce much effect on the flux where the iron is highly saturated, as is the case at low speed. The conditions are much different, however, at high speed and a weak field. The iron is worked so low that there is practically nothing but the air-gap ampere-turns present. This makes the flux very sensitive to any changes in excitation; also the total excitation required is so small that the short-circuit ampere-turns may form an appreciable percentage. Practice has shown that, although a motor may not be over-compensated enough to cause sparking, the speed regulation may be changed from 10 to 15 percent, often resulting in a rising speed curve. Thus, as previously stated, the motor should be designed for the high-speed operation. Even when the commutating coil is adjusted for the best average conditions at high speed, the effect of the short-circuit current will still be noticeable and will show up in the shape of the curves. At light loads with over-compensation, as at *b*, Fig. 2, the speed will be increased slightly, while for heavy loads it will drop. The action of the commutating pole will thus tend to make the speed curve from no load to full load more nearly a straight line, but will cause it to drop more at heavy loads. The dotted curve *c*, Fig. 1, shows the final curve as obtained after taking account

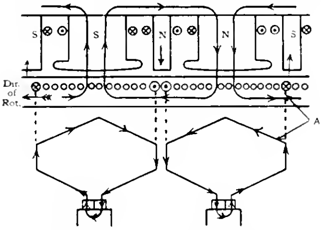

FIG. 3—SCHEMATIC DIAGRAM OF PATHS OF COMMUTATING-POLE FLUX

of all four factors,—IR drop, distortion, local currents, and compensating coil excitation.

It should be borne in mind, when asking for guarantees on speed regulation, that the greatest drop in speed occurs from no load to one-quarter load. Usually the friction of the driven machine is great enough to bring the speed down to the flat part of the curve, so that for the actual working range the regulation will be very close.

COMPOUND-WOUND MOTORS FOR ADJUSTABLE SPEED

The difficulty in designing compound-wound motors for adjustable speed lies in the fact that it is impossible to obtain the same regulation at all speeds. At the low speed the field is worked above the knee of the saturation curve, and a strong series coil is required to obtain the full-load flux. At high speed the field is worked very low and the same series coil will give a great deal more flux than is wanted. A machine having 20 percent speed regulation at low speed may be expected to have at least 40 or 50 percent at double speed. It is plainly evident that only small ranges of adjustment can be obtained, for otherwise the no-load speed will rise above the safe mechanical limit of the armature.

Some Features of Commutating-Pole Railway Motor Construction

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Certain features of the design of the modern street car motor depend directly on the design of the car. Size of wheels, length of wheel base, position of brake rods, etc., are frequently the deciding factors in the selection of armature diameter or type of field windings. Other important design features of the motor may also be affected.

The use of small wheels has introduced new problems in motor construction which have had to be met by rearranging and proportioning the material to the best advantage to suit the new conditions. One of the first problems confronting the designer is to overcome the handicap of shorter gear center distance which naturally goes with small-wheel diameter. One way of doing this is to omit the commutating pole located on the axle side of the motor and proportion the remaining commutating poles so that they will produce the same effect with regard to commutation as would be obtained ordinarily with the full number of poles.

The conditions leading to this design can better be shown, perhaps, if the relations which exist between wheel size, gear reduction, tractive effort developed by the driving wheels, and power drawn from the line, are reviewed.

Mechanical Considerations—In city service, where economy of power requires that the accelerating current be as low as possible, it is desirable in most cases to use the maximum gear reduction possible, as this gives the maximum tractive effort at the wheel periphery for any given motor torque, and consequently for any given amount of power drawn from the line. Therefore, it is desirable to use as small a pinion as is consistent with the required strength under the teeth; and as large a gear as will permit proper clearance beneath the gear case. A reduction in wheel diameter requires a corresponding decrease in the diameter and number of teeth of the gear to maintain sufficient clearance beneath the gear case. Using a minimum sized pinion, as before, to maintain maximum reduction, this decrease of gear diameter results in a shortening of the gear center distance, which means bringing the center of the armature closer to the center of the axle. This, in turn, results in a restriction of space in the axle region and a difficulty in obtaining room for the field winding. Omitting the commutating pole on the axle side permits the armature to be brought nearer the axle. If, however, only one pole is omitted, an unbalanced magnetic pull results, which in most cases can be obviated best by omitting the opposite pole as well.

Electrical Considerations—In a machine having four commutating poles and four exciting poles about 70 percent of the turns on the commutating poles serve to simply neutralize the magnetomotive force of the armature. The remaining 30 percent are for the purpose of producing sufficient field in the commutating zone to neutralize the sparking voltage in the short-circuited coils. Therefore, in omitting, say, two of the commutating poles, it is necessary only to add to the two remaining poles the magnetizing turns, or about 30 percent of the turns of the poles omitted.* In actual practice it is necessary to add a little more than 30 percent and also to somewhat lengthen the commutating poles axially to take care of saturation, etc., but a considerable net saving in copper and iron is secured. Efficient designs, using half as many commutating poles as main poles, may be worked out for motor sizes up to about 50 horse-power. Above this size the commutating poles are apt to become bulky and cumbersome, thus involving complication from the standpoint both of heating and manufacture. This design, besides saving in space, has an advantage in reduced weight, copper loss and less likelihood of grounds because of there being fewer coils to ground.

Magnetic Considerations—It is common practice to think of the action of the commutating poles as being independent of the main poles. This is true only in the case of machines having the same number of commutating poles as main poles and when the windings on the latter are symmetrical, that is, when each pole has the same number of turns. This assumption, however, would lead to very erroneous results in the case of machines in which the number of commutating poles is different from the number of main poles, or when the number of turns on the main poles is not the same for each pole, as will be shown in the following analysis. To shorten the analysis, one case only, rather than a general case, will be considered, viz., a four-pole motor having two commutating poles. The magnetic flux is distributed as in Fig. 1.

A physical conception of the magnetic relations involved may be had by considering the analogy of the electric circuit as shown in Fig. 2. If the voltage of battery *A* and *C* be kept constant and that of *B* raised by the addition of cells the latter will supply more current to *C* than before and *A* will supply less. So, also, with the magnetic circuit shown. If, for instance, the strength of commutating pole *2* be increased, that of

*See "Two Commutating Poles on Four-Pole Motors," in the Journal for June, 1915, p. 290.

main pole *3* will be also increased, and that of main pole *1* will be decreased.

Perhaps a clearer physical conception of the influence of the main and commutating poles upon each other may be obtained by considering the flux produced by each independent of the other. Then by superimposing

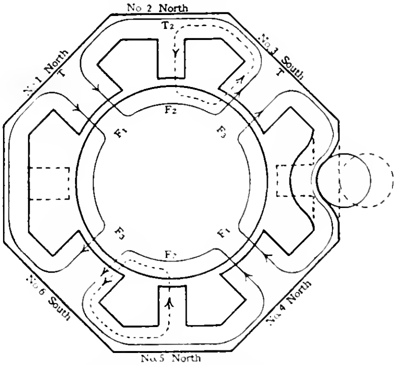

FIG. 1—DISTRIBUTION OF MAGNETIC FLUX IN A FOUR-POLE MOTOR HAVING TWO COMMUTATING POLES

Full lines represent balanced fluxes.
Dotted lines represent superimposed unbalanced fluxes.

the two upon each other the actual distribution may be obtained. On this basis, the flux produced by the ampere-turns on commutating pole *2* (Fig. 1) has two return paths in parallel through main poles *1* and *3*. Similarly the return paths for pole *5* are through poles *4* and *6*. Neglecting effect of saturation, the total reluctance corresponding to flux F_2 is that of the commutating pole gap plus the resultant reluctance of the parallel paths through *1* and *3*. Since the reluctance of the two parallel paths is equal, the flux in these two paths due to the ampere-turns in the commutating pole only, must also be equal. The flux in pole *1*, due to the commutating pole, is opposed to that produced by the ampere-turns T on pole *1*, and the flux F_1 is, therefore, equal to the difference of the flux produced in this pole by ampere-turns T only and the flux produced in this pole by ampere-turns T_2 only. Similarly, flux F_3 in pole *3* is equal to the sum of the separate fluxes produced in this pole by ampere-turns T and ampere-turns T_2.*

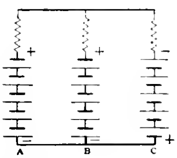

FIG. 2—ELECTRIC CIRCUIT ANALOGY TO MAGNETIC FLUX OF FIG. 1

With low saturation in the iron parts of the circuit the strengthening effect of the commutating pole upon one main pole is offset by its weakening effect upon the other, and the relative effect upon the speed of the machine is *nil*. With fairly high inductions, however, on account of the saturation characteristics of the iron, the strengthening effect on pole *3* will be less than the corresponding weakening on pole *1*, which will result in a net reduction in the main flux and a corresponding increase in speed. Usually the extent of this increase is not serious, although it is quite appreciable.

It is of interest to note the distribution of flux in the different portions of the frame, as compared with that of a non-commutating pole machine. It is obvious that between poles *3* and *4* the flux will be the same. Between *2* and *3* the total flux carried by the frame is greater than on non-commutating machines by one-half of the commutating pole flux. Between *1* and *2* it is less by one-half of the commutating pole flux. It therefore follows that the frame may be made of smaller section between *3* and *4* than between *1* and *2* or *2* and *3*. The latter two sections will, however, be made the same, because with reversal of direction of rotation the condition between *1* and *2* will be the same as shown between *2* and *3* in the diagram.

MOTORS FOR ELEVATED AND SUBWAY CARS

In the design of railway motors of about 150 horsepower and up, such as are used in elevated and suburban service, as a rule the motor space is not as restricted as in the case of surface cars. However, cases occasionally arise where the gear center distance must be made shorter than normally would be required.

Mechanical Considerations—The conditions here involved are different from those in the smaller motors for surface cars, in that it is customary to have a main pole at the axle instead of a commutating pole. It will not be within the scope of this article to discuss at length the various advantages of having this arrangement on the larger motors. One advantage may be mentioned, namely, that the brushes and brushholders are more readily accessible, inspection being made usually from underneath the car instead of through a trap in the floor of the car, as is the case generally with street cars.

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*Supplementing the above physical conception of the relation existing between the main and commutating poles, a mathematical analysis may be made as follows:—

In Fig. 1 let

T = Ampere-turns on main poles Nos. 1 and 3.
T_2 = Ampere-turns on commutating pole No. 2.
F_1 = Flux in Pole No. 1.
F_2 = Flux in pole No. 2.
F_3 = Flux in pole No. 3.
R = Reluctance of the air-gap in the main poles (Nos. 1 and 3).
KR = Reluctance of the air-gap under the commutating pole (No. 2), where K is a constant approximately equal to the area of the main gap divided by that of the commutating pole air-gap.

Then, applying the law of magnetic potentials, viz. that algebraic sum of magnetomotive forces in any circuit must equal algebraic sum of magnetic drops.

For the circuit through poles *1* and *2*, $K_1T - K_1T_1 = RF_1 - KRF_2$ (1)
For the circuit through poles *2* and *3*, $K_1T_2 + K_1T = RF + KRF_2$ (2)
For the circuit through poles *3* and *1*, $KT + K_1T = RF_1 + RF_3$ (3)

Where $K_1 = \frac{4\pi}{10}$

Also $F_1 + F_2 = F_3$ . . . . (4)

The solution of these equations being somewhat lengthy will be omitted here, but the results are as follows:—

$$F_2 = \frac{2 K_1 T_2}{R(1+2K)} \qquad (5)$$

$$F_1 = \frac{K_1 T}{R} - \frac{K_1 T_2}{R(1+2K)} = \frac{K_1 T}{R} - \frac{F_2}{2} \qquad (6)$$

$$F_3 = \frac{K_1 T}{R} + \frac{K_1 T_2}{R(1+2K)} = \frac{K_1 T}{R} + \frac{F_2}{2} \qquad (7)$$

The location of the main pole at the axle requires that the brushholders be rotated from the 45 degree lines, bringing them nearer the axle, where they are more readily inspected.

Shortening the gear center distance results in a reduction of the space for the main field winding at the axle side. This condition may be overcome by proportioning the exciting coil at the axle side with as many turns as the restricted space will permit, and designing the top and bottom coils with a greater number of turns, such that the sum of the ampere-turns on the side and top coils will be sufficient to produce the required flux. The coil on the other side of the motor opposite the axle should, of course, have the same number of turns as that on the axle side.

It is of interest to note that in the above method of winding, the design of the commutating poles is somewhat influenced by the number of turns on the main field coils. With the same number of turns on all main poles the design of the commutating poles would be practically independent of that of the exciting coils.

Magnetic Consideration—The distribution of flux in the various circuits is shown in Fig. 3.* Here again a physical conception of the conditions involved may be had by considering that the main coils of poles *3* and *7* are made up of two sections, one section having the same number of ampere-turns as poles *1* and *5*, and the other having the difference between the turns of these poles ($T_3 - T_1$). This results in a machine in which the flux is produced by balanced windings from both main and commutating poles, superimposed upon which is a flux due to $T_3 - T_1$ turns on poles *3* and *7*. By calculating these fluxes as independently and superimposing one upon the other the actual flux distribution may be determined.

With the same number of commutating poles as main poles, as shown in Fig. 3, and with balanced windings, the effect of the commutating poles upon the main poles, and vice versa, is *nil*, because the effects are all equal and balanced one against the other. With unsaturated circuits the flux in main poles may be calculated as if the commutating poles did not exist, and vice versa.

Considering now the machine as if there were no windings except $T_3 - T_1$ ampere-turns upon poles *3* and *7*. The flux in pole *3* has return paths in parallel through poles *2* and *4* and through one-half of poles *1* and *5*. Thus the total reluctance against the flux in pole *3* is that of the air-gap under pole *3* in series with the parallel paths *2*, *4*, one-half of *1*, and one-half of *5*, and the flux is distributed between these air-gaps inversely in proportion to their respective reluctances.

The following deductions are obvious from the diagram:—First, the flux in main poles *3* and *7* exceeds that in main poles *1* and *5* by an amount equal to twice the flux induced in each of the commutating poles by the unbalanced magnetomotive force due to $T_3 - T_1$ turns on poles *3* and *7*. Second, the flux in com-

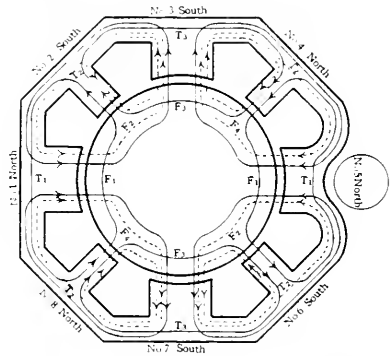

FIG. 3—DISTRIBUTION OF THE MAGNETIC FLUX OF A MOTOR HAVING FOUR MAIN AND FOUR COMMUTATING POLES

Full lines represent balanced fluxes.
Dotted lines represent superimposed unbalanced fluxes.

mutating pole *2* is weakened and that in commutating pole *4* is strengthened by the flux induced in them by $T_3 - T_1$. These two statements are equivalent to saying that the magnetic unbalance is proportional to the difference in the number of turns on the main poles. Third, if the unbalancing of the main field turns is carried so far as to make the flux induced in pole *2* by the ampere-turns $T_3 - T_1$ equal or exceed that induced in this pole by T_2, the flux in commutating poles *2* and *6* will be completely neutralized or even reversed.

These statements are all based on the assumption of unsaturated magnetic circuits. When the magnetic circuits are partly saturated, the difference between flux in poles *1* and *3*, and also in poles *2* and *4* will be reduced. In other words, the weakening of poles *2* and *6* is greater than the strengthening of poles *4* and *8*, with a resultant weakening of total commutating flux. This can be compensated for by additional turns on the commutating poles or by more liberal design in other respects.

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*The relation between these fluxes may be determined mathematically as follows:—

T = No. of ampere turns on main poles at side of motor,
T_2 = No. of ampere turns on main poles at top and bottom of motor,
T_1 = No. of magnetizing ampere turns on each commutating pole,
R = Magnetic reluctance of main pole gaps,
KR = Reluctance of commutating pole gaps,
F_1 = Flux in side main poles, *1* and *5*,
F_3 = Flux in top and bottom main poles, *3* and *7*,
F_2 = Flux in commutating poles, *2* and *6*,
F_4 = Flux in commutating poles, *4* and *8*.

The total positive flux including main and commutating, must equal the total negative flux. Therefore:—

$$F_1 + F_4 = F_2 + F_3 \qquad (1)$$

Applying the law of magnetic potentials before mentioned and again assuming non-saturated circuits, the following equation is obtained.

For circuit through poles *1* and *3*, $K_1T_1 + K_1T_3 = F_1R + F_3R$ (2)

where, $K_1 = \frac{4\pi}{10}$

For poles Nos. *2* and *3* $K_1T_2 - K_1T_3 = KF_2R - F_3R$ (3)
For poles Nos. *3* and *4* $K_1T_2 + K_1T_3 = KF_4R + F_3R$ (4)

Solving these equations we obtain the following:

$$F_1 = \frac{K_1\ (T_1+T_3)}{2R} - \frac{K_1\ (T_3-T_1)}{2R\ (1+K)} \qquad (5)$$

$$F_3 = \frac{K_1\ (T_1+T_3)}{2R} + \frac{K_1\ (T_3-T_1)}{2R\ (1+K)} \qquad (6)$$

$$F_2 = \frac{K_1\ T_2}{KR} - \frac{K_1\ (T_3-T_1)}{2R\ (1+K)} \qquad (7)$$

$$F_4 = \frac{K_1\ T_2}{KR} + \frac{K_1\ (T_3-T_1)}{2R\ (1+K)} \qquad (8)$$

The Circle Diagram for Single-Phase Circuits

Charles Fortescue

The problem of determining the potential drop over a single-phase transmission line, transformer or other single-phase circuit which is delivering a given kilowatt load is complicated by the fact that the current which is necessary to carry the given load varies with the potential drop and the power-factor, each of which is varied in turn by a change in the current. The potential drop or terminal voltage for any given condition can, of course, be calculated. However, the calculation is complicated and, where voltage drops under varying conditions are to be determined, is laborious.

The circle diagram for the determination of delivered potentials for any given current at any desired power-factor has been previously described.* By means of additional arcs drawn on this diagram it is possible to determine at a glance the terminal voltage and current which will deliver a given load in kilowatts at the end of a given single-phase transmission line or at the terminals of a transformer or other apparatus having both a reactive and resistance drop.

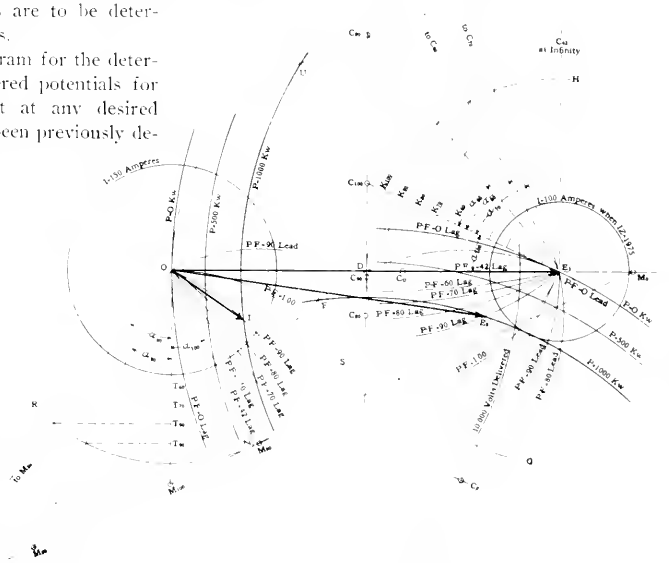

FIG. 1—A CIRCLE DIAGRAM FOR SINGLE-PHASE CIRCUITS

As a typical example of the construction and application of such a diagram, a single-phase transmission line 16 miles long will be assumed, consisting of two No. 0000 wires spaced 18 inches apart. A constant potential of 11 000 volts will be impressed on the end of this line. Such a line will have a resistance of 0.518 ohms per mile and a reactance of 1.12 ohms per mile, giving an impedance of 1.234 ohms per mile, or 19.75 ohms total.

To construct the diagram, lay off OE_1 equal to the no-load voltage to some convenient scale. In all ordinary cases this will be equal to the impressed voltage. The position of the terminal of the vector representing delivered voltage depends upon any two of three factors, viz., current, power-factor and power. Three sets of loci may therefore be plotted, the intersection of any two such loci determining the location of the vector E_2.

LOCI FOR VARIOUS CURRENTS

When the primary e.m.f. is fixed, the locus of E_2 for a given load current is a circle with its center at E_1 and a radius equal to the product of the impedance of the circuit into the given current. In Fig. 1 such a circle is shown for a current of 100 amperes, giving 1975 volts impedance drop. If the interest lies solely in the power to be delivered, which is frequently the case, then the circles for loci at different currents may be entirely omitted.

LOCI FOR VARIOUS POWER-FACTORS

The locus of E_2 for any given power-factor is a circle which must pass through E_1 at no-load through O with a direct short-circuit. Hence the center of this circle must lie on the perpendicular bisector of OE_1. The location on this line of the centers corresponding to the various power-factors is determined as follows:—Lay off along this line a distance of DC_{100} such that the ratio DC_{100} to DE_1 equals the ratio of the resistance to the reactance of the circuit. An arc drawn through E_1 with a center at C_{100} represents the locus of E_2 for all loads of 100 percent power-factor. The centers C_{90}, C_{80}, etc., for other power-factors are obtained by laying off angles α_{90}, α_{80}, etc. $= \cos^{-1} 0.90$, $\cos^{-1} 0.80$, etc., respectively, making the angle either lag or lead $C_{100}E_1$, according as the power-factor is lagging or leading; or the centers may be determined graphically by laying out along the radius E_1K_{100}, of circle GDH (which is drawn tangent to the perpendicular bisector C_0D with center at E_1), a distance which for C_{90} would be 90 percent of the radius E_1K_{100}. The perpendicular erected at K_{90} then represents the chord of the double angle of lag and lead represented by a power-factor of 90 percent. Other angles are laid off similarly. The loci of E_2 for the various power-factors are then determined by the inter-

*See article on "The Circle Diagram for Single-Phase Transformers," by Mr. Charles Fortescue, in the Journal for August, 1914, p. 449.

section of the power circle with the power-factor circles passing through E_1, with centers at C_{90}, C_{80}, etc.

LOCI FOR VARIOUS LOADS

The locus of E_2, for any given amount of power delivered, is a circle having for its center the center C_0 of the zero power-factor circle. The radius* is equal to $r_E = \sqrt{\frac{E_1^2}{4 \cos^2 \alpha} - \frac{PZ}{\cos \alpha}}$. To obtain r_E $\left(\text{since } C_0E_1 = \frac{E_1}{2 \cos \alpha}\right)$ describe on C_0E_1 a semicircle, and from E_1 lay off a chord E_1F equal to $\sqrt{\frac{PZ}{\cos \alpha}}$ on the same scale as IZ. F is a point on the required locus and C_0F is the radius r_E, for a given power P.

THE CURRENT DIAGRAM

The loci of the various current vectors can be determined by similar groups of circles representing current, power-factor and power loci. The locus of the vector for a particular current is a circle with O as a center and a radius equal to the desired current laid off to a suitable scale. The loci for various power-factors are determined by laying off OM_{100} at right angles to OE_1 and laying off angle $\alpha_{100} = \alpha_{10}$, of the voltage diagram. A circle RNS is then drawn, with O as its center, whose radius is to the radius of a given current circle as DE_1 is to the impedance drop due to that current. In other words, $ON : I = DE : IZ$ laid off to the correct current and voltage scales. A line is then drawn tangent to this circle and perpendicular to ON. The intersection of this line with OE_1 continued is the center of the zero power-factor circle. The intersection of this line with OM_{100} is the center of the 100 percent power-factor circle. The centers of the circles for the other power-factors are obtained by laying off the suitable angles in the same manner as in the voltage diagram.

The radii* of the power loci circles are determined by making them bear the same relation to the radii of the same circles in the voltage diagram as the radii of the respective zero power-factor circles. In other words, $r_1 : r_E = OM_0 : E_1C_0$. Or to obtain the required radius describe a semicircle on M_0O, and from O lay off a chord OU (equal to $\sqrt{\frac{P}{Z \cos \alpha}}$ on the same scale as I) on this semicircle. Then I is a point on the required locus and M_0U is the required radius.

USE OF DIAGRAMS

The intersection of any two loci determines the location of the vector of terminal volts or current. Thus in Fig. 1 a vector is drawn as a heavy line to represent

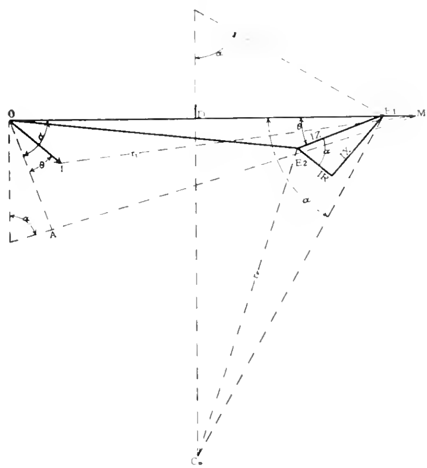

FIG. 2—SIMPLIFICATION OF CIRCLE DIAGRAM OF FIG. 1

E_2 with a load of 1000 kilowatts at a power-factor of 90. The current corresponding to this load is shown in

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*In Fig. 2, a part of the main diagram, Fig. 1 is drawn separately for simplicity.

$$E_2 = E_1 - IZ\ (\cos.\ \theta + j \sin \theta)$$

$$I = I\ [\cos\ (\alpha - \theta) - j \sin\ (\alpha - \theta)]$$

$$P - j\,Q = E_2\ I\ [\cos\ (\alpha - \theta) + j \sin\ (\alpha - \theta)]$$

$$= I\ E_1\ [\cos\ (\alpha - \theta) + j \sin\ (\alpha - \theta)] - I^2Z\ [(\cos \alpha + j \sin \alpha)]$$

$$P = (I\ E_1 \cos\ (\alpha - \theta) - I^2Z \cos \alpha) \ldots \qquad (1)$$

The equation of the circle having C_0 as center and C_0E_2 as radius is obtained as follows:—

$$C_0\ E_1 = \frac{E_1}{2 \cos \alpha}$$

Denote C_0E_2 by r_E.

Then $r^2_E = [C_0E_1 - IZ \cos\ (\alpha - \theta)]^2 + [IZ\ (\sin \alpha - \theta)]^2$

$$r^2_E = \frac{E^2_1}{4 \cos \alpha^2} - \frac{E_1IZ}{\cos \alpha} \cos(\alpha - \theta) + (IZ)^2$$

$$I^2Z \cos \alpha + \frac{E_1^2}{4\ Z \cos \alpha} - I\ E_1 \cos\ (\alpha - \theta) = \frac{r^2_E \cos \alpha}{Z}$$

or $IE_1 \cos\ (\alpha - \theta) - I^2\ Z \cos \alpha = \frac{E_1^2}{4Z \cos \alpha} - \frac{r^2_E \cos \alpha}{Z} \ldots\ldots (2)$

which is the equation of the circle having C_0 as center and radius C_0E_2 in turns of the variable (IZ). But from (1)

$$I\ E_1 \cos\ (\alpha - \theta) - I^2Z \cos \alpha = P$$

and therefore the locus of P = a constant is the above circle.

To find r_E, substitute (1) in (2).

$$r^2_E \frac{\cos \alpha}{Z} = \frac{E_1^2}{4\ Z \cos \alpha} - P \qquad (3)$$

$$r^2_E = \frac{E_1^2}{4 \cos^2 \alpha} - \frac{P\,Z}{\cos \alpha} \qquad (4)$$

---

*The equation of the circle having M_0 as center and M_0I as radius is obtained as follows:—

$ON = M_0O \cos \alpha = \frac{E}{2\,Z}$ by construction.

Then $M_0O = \frac{E_1}{2\ Z \cos \alpha}$

Let r_1 be the radius M_0I

$$r^2_1 = \left(\frac{E_1}{2\ Z \cos \alpha} - I \cos\ (\alpha - \theta)\right)^2 + I^2 \sin^2\ (\alpha - \theta)$$

$$= \frac{E_1^2}{4\ Z^2 \cos^2 \alpha} - \frac{E_1I}{Z \cos \alpha} \cos\ (\alpha - \theta) + I^2$$

$$I\ E_1 \cos\ (\alpha - \theta) - I^2Z \cos \alpha = \frac{E_1^2}{4\ Z \cos \alpha} - r_1Z^2 \cos \alpha =$$

a constant

which is the equation of the circle having M_0 as center and M_0I as radius in terms of I.

Since the left hand value of the equation is equal to P, the above circle is the locus of P = a constant. To obtain r_1 we have

$$r_1^2 = \frac{E_1^2}{4\ Z^2 \cos^2 \alpha} - \frac{P}{Z \cos \alpha}$$

magnitude and direction by the vector drawn to the intersection of the 1000 kilowatt and the 90 percent power-factor loci of the current diagram. This current can also be determined in magnitude, but not direction, by measuring the distance E_2E_1 in volts and dividing by the impedance; this affords an easy check on the accuracy of the diagram.

It will be evident both from the voltage and current diagrams that it is impossible for the assumed circuit to deliver 1000 kilowatts at 60 percent power-factor or less, as the 1000 kilowatt locus reaches the perpendicular bisecter of OE_1 without interesting the 60 percent power-factor locus. This is an example of the well-known law that, with a constant impressed voltage, the maximum amount of power may be obtained from a circuit when the external resistance or impedance equals the internal resistance or impedance; in other words, when the voltage drop equals the delivered voltage.

The diagram is, of course, entirely reversible. For instance, if it is desired to determine the amount of power at a given power-factor which can be delivered by the given circuit at a given secondary voltage, draw a circle with O as a center and the desired voltage as a radius, as shown in Fig. 1, by the circle marked 10 000 volts delivered. The distance from the intersection of this circle with the power-factor circle (as, for instance, power-factor = 90) to C_0 gives the value of r_E for the desired amount of power, and knowing r_E the value of the power can readily be calculated from equation (3).

The power-factor represented by the power-factor circles on the diagram and throughout the above discussion is the power-factor of the load, the angle of lag or lead being the angle between the vectors E_2 and I. The power-factor of the generator, transformer or other apparatus feeding the circuit for which the diagram is drawn corresponds, of course, to the angle between E_1 and I. In case the delivered no-load voltage is not equal to the impressed voltage as would, for instance, be the case with an underground high-voltage cable, the vector E_1 must be drawn to represent the delivered no-load voltage, and a new vector E can be drawn to represent the impressed voltage in both phase position and magnitude. As the whole diagram is drawn on the basis of a constant impressed voltage, the vectors E and E_1 will both be fixed in position. In this case, of course, the power-factor of the apparatus supplying the voltage will correspond to the angle between E and I.

A study of this diagram reveals many interesting relations between the current and voltage of a single-phase circuit. For example, it is at once evident that at high power-factors the delivered voltage will lag behind the impressed voltage considerably, the effect of the impedance of the line being to produce a phase displacement rather than a drop in voltage. The voltage drop is maximum and the phase displacement of the delivered voltage zero when the power-factor of the load equals the power-factor of the circuit for which the diagram is drawn when short-circuited. For still lower power-factors, the delivered voltage will lead the impressed voltage. With leading power-factors, it is possible for the delivered voltage to exceed the no-load voltage, a condition which makes it evident that voltage drop in an alternating-current line bears no relation to the power loss in the line.

Automatic Controllers

FOR ADJUSTABLE-SPEED, DIRECT-CURRENT MOTORS DRIVING PAPER MACHINES

R. T. Kintzing
Industrial Control Dept.,
Westinghouse Electric & Mfg. Company

Uniformity of production from a paper machine requires constant speed. On the other hand, for the manufacture of a variety of qualities and thicknesses of paper in one machine the speed of the machine must be adjustable over a wide range. The problem of electric drive is to obtain a speed range of approximately 10 to 1 economically; to maintain constant speed with a given load; and to provide for such gradual changes of speed in accelerating and decelerating that the paper will not be torn.

It is generally admitted that these severe operating conditions can be most economically met by the use of adjustable-speed, direct-current motors with shunt field speed control. Small motors can be built which have a field control speed adjustment of 5 to 1, but they are relatively large and expensive, and sizes larger than 50 horse-power are not commonly built with such a wide speed range. To secure a speed range of 10 to 1, therefore, requires an additional means of speed adjustment. A resistance in series with the armature is wasteful of power. The use of constant potential, multi-voltage power supply with two or three voltages offers an apparent method of increasing the speed range of such motors, but the difficulty of obtaining smooth acceleration limits its practical application. The control scheme shown in Fig. 3 combines the use of adjustable-speed motors with a variable potential power supply having a wide range of adjustment, and thereby makes possible the use of economical sizes of motors and steady speed control.

In this system the direct-current power is obtained from a motor-generator set which usually consists of three machines on a common bedplate, as shown in Fig. 1, namely,—the alternating-current motor; the direct-current generator; and the exciter (which is used for the excitation of the generator, the adjustable-speed

motor and the alternating-current motor field in case the driving motor is a synchronous machine). The exciter voltage is held constant, and is also used to provide power for the operation of magnetic contactors, relays, etc., on the control board. A switchboard with the necessary meters, switches and starting device is used for the control of this set.

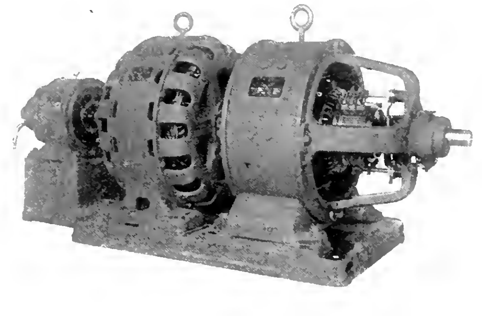

FIG. 1—MOTOR-GENERATOR SET
Used with paper-machine controller.

The controller proper, shown in Fig. 2, consists of a motor-driven combination field-rheostat for varying the direct-current generator voltage and for shunt field control of the direct-current motor; a two-pole knife switch for connecting motor and generator together; a magnet-operated contactor for the main line current, and all necessary relays and interlocks.

FIG. 2—AUTOMATIC CONTROLLER FOR DIRECT-CURRENT, ADJUSTABLE-SPEED, PAPER-MACHINE MOTOR

All operations of the controller are automatic and are controlled from push buttons. A standard controller includes *Start*, *Fast*, *Slow*, *Safe*, *Run* and *Stop* push buttons. In normal operation the direct-current generator voltage is so low when starting that when the motor and generator are connected together no external resistance is needed to limit the motor current. When the *Start* button is pushed, the main line contactor closes and the generator voltage builds up to the value necessary to give the minimum paper speed. The motor continues to run at this speed until the operator presses the *Fast* button, which drives the rheostat arm around and builds up the generator voltage at a rate which is limited by the armature current to prevent too rapid acceleration. As soon as the rheostat arm moves beyond the point of full generator voltage, the field of the adjustable-speed motor is gradually weakened and the motor speed is correspondingly increased. The opposite result is obtained by pushing the *Slow* button, which causes the arm to reverse and move in the opposite direction. The *Stop* button opens the control circuit and thereby disconnects the motor from the generator and cuts in all the generator field resistance. Similarly,

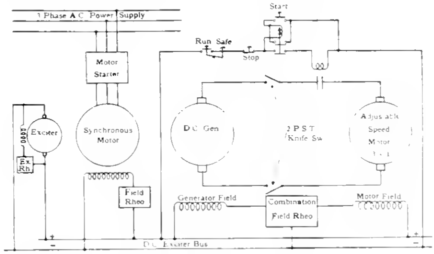

FIG. 3—SCHEME OF CONNECTIONS OF DIRECT-CURRENT PAPER-MACHINE CONTROLLER

when the *Safe* button is pushed the entire control circuit is interrupted, but in this case it remains open until the operator pushes the *Run* button. After this, in order to start, it is necessary to push the *Start* button

If the *Start* button is pushed when the rheostat arm is in the high-speed position, the motor will automatically accelerate to this speed at a safe and predetermined rate. If the motor is overloaded, an overload relay in the motor circuit operates to disconnect the motor and shuts down the paper machine. Ordinarily, a speed-indicating meter is mounted on the wall near the main push-button station.

These automatic controllers give a wide range of speed economically and, with the large number of points of acceleration, provide for very gradual changes of speed, conditions which are essential to the successful operation of paper-making machinery.

Reactive-Factor

In vector representation any vector may be resolved into components for convenience of consideration. The current in an alternating circuit is generally treated as a sine wave subject to vector rules; so, for convenience it is often considered as being composed of two components, the active component representing the actual power of the circuit, and the reactive component representing the magnetic and capacitance effects. The reactive component, representing no true power, is at right angles to the active component which is in phase with the voltage. For different phase relations of current and voltage the active and reactive current components are as shown in Table I.

The power in the circuit is the product of the active component of current and the voltage. By the definition of power-factor, the power in a circuit is also the product of power-factor, current and voltage. This makes the power-factor equal

TABLE I—RELATION OF POWER-FACTOR TO REACTIVE-FACTOR

Phase Angle	Percent of Total Current	
	Active Component	Reactive Component.
0	100	0
5 – 45′	99.5	10
8 – 7′	99	14.1
9 – 57′	98.5	17.3
11 – 29′	98	19.9
18 – 12′	95	31.2
25 – 50′	90	43.6

to the ratio of active component to total current. An analogous term is reactive factor, which is equal to the ratio of reactive component to total current. Reactive factor times total k.v.a. gives the reactive or non-power producing k.v.a.

It is evident from Table I that with small phase angles the power-factor decreases slowly while the reactive-factor increases rapidly. In operating converters it is very important to have current and voltage as nearly in phase as possible. For this reason reactive-factor meters are frequently used instead of power-factor meters. If an operator is told to run at 100 percent power-factor he will not be much worried if his meter reads 99 percent, but if he is told to run at 0 percent reactive-factor he will hardly feel easy when his meter registers 14 percent reactive-factor. Since the reactive or non-energy-producing current is what must be kept down, it is quite logical to use meters which read this reactive current. This is especially true with rotary converters, in which a small phase displacement produces a large increase in heating of the tap coils.

Compounding Rotary Converters

If a constant alternating e.m.f. is applied to a rotary converter it will be found that the direct e.m.f. will fall as the load is applied, due to drop in the windings. It is often desirable to keep this voltage constant without boosting the alternating voltage. This can be done by compounding, that is by using a series field. As load comes on the field is strengthened, making the armature draw a leading current as in a synchronous motor. There is always some reactance in the line and transformers which gives the desired effect as follows:—

With current in phase with the voltage the counter e.m.f. E_c is less than the line e.m.f. E_1 due to impedance drop. With lagging current, Fig. 1, E_c is also less than E_1, but with leading current, Fig. 3, and sufficiently large IX drop, E_c becomes larger than E_1. The direct voltage of the converter is equal to the maximum value of E_c, so when the field is strengthened, resulting in a leading current, the direct voltage is raised. Over-compounding is seldom attempted, as it requires too much reactance in the alternating-current side and makes the converter heat, due to operating at power-factors below unity.

This same boosting of voltage shows also in the regulation of transformers. When carrying unity power-factor load the IX drop has little effect on the regulation, as it is at right angles to the voltage, Fig. 2. With low power-factors the IX drop has the chief effect, and the IR drop for the same reason

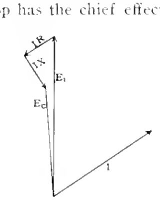

FIG. 1

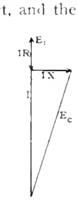

FIG. 2

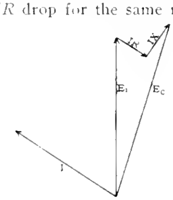

FIG. 3

relatively little. As before, if the current leads the e.m.f. a rising voltage characteristic may result, due to the position of the IX drop.

Where a considerable compounding is desired from a rotary converter, a transformer with artificial reactance is provided,* which gives a considerable reactive drop at low power-factors (under-excitation of the converter) and a rise in voltage with leading power-factors (over-excitation of the converter).

Action of Synchronous Motor on Varying Field Excitation

In transmission line work it is desirable to maintain high power-factors. In order to do this a synchronous motor is often used. If a synchronous motor has a current in its armature in phase with its e.m.f., the armature reaction will be "cross magnetizing," as in a direct-current machine with brushes on the neutral. If the current lags behind the e.m.f. it will reach its maximum value after the armature has moved beyond the position shown in Fig. 1, and the armature reaction

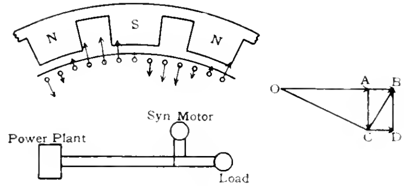

FIG. 1

will strengthen the field. Conversely, a leading current will tend to demagnetize the field. Suppose we have a motor on the end of a line. If we increase the field current the counter e.m.f. will tend to rise, since the speed must stay constant. We know that it cannot rise above line voltage, as then it could not receive power from the line. In order to counteract the increase in flux due to increased field current, enough leading current will flow in the armature to overcome the e.m.f. of the additional field current. If this leading current is equal to the lagging component of the load current, the line current will be

*See article on "Leakage Reactance," in the JOURNAL for August, 1915, p. 383.

in phase with the voltage, and the generator and line will operate at unity power-factor. Thus let OA represent the active component of the load current, AC the lagging reactive component, and OC the total load current without the synchronous motor. CD represents the active component of the motor current, DB the leading reactive component, and CB the total motor current. Adding OC and CB we get OB, which is the line current, which has no reactive component if DB and AC are equal.

Commutator Construction

Commutators are made from hard-drawn, wedge-sectioned copper bars and ordinarily are held together by V-rings, which fit into the commutator on each end and are insulated from it by means of a mica-moulded form. The rear V-ring is usually cast in one piece with the armature spider, especially in small machines, while the front V-ring is removable. There are two general methods of clamping these V-rings together,—by a ring nut or by heavy clamping bolts.

The bolted construction is used on large sizes, where a ring nut would be expensive and hard to use. It is also used in some cases on motors of moderate size that are subjected to severe mechanical stresses and vibration in service. It gives a more rigid construction, but cannot be applied easily to small commutators on account of lack of space.

The ring nut is used on most motors of small and medium size on account of its simplicity and low cost. If care is taken to have the bars of uniform length and the mica of uniform thickness, it is satisfactory, otherwise some bars will be clamped tighter than others when the ring is screwed tight, thus allowing the bars to loosen in service.

The commutator necks, when not an integral part of the commutator bars, are usually hard-rolled copper straps, riveted and soldered to the bars with a special high-melting solder. By using a localized flame, the temperature of the bar at the V is not raised high enough to destroy the temper given to the copper by the drawing process. These necks are usually arranged so that, in addition to connecting the windings to the commutator, they act as blowers and assist in radiating the heat developed at the brushes, thus keeping the commutator cool.

In building a commutator the bars and mica sheets are assembled in steel clamps, turned and clamped between the V-rings. They are then put through a continued heat and pressure treatment, which seasons the commutator thoroughly. The bond of shellac or other ingredients which is used in the process of building up the mica strips to the required thickness is driven off during the seasoning process, leaving the insulation strips between the commutator bars hard and dry. The mica V insulation which is used in moulded form on the ends of the commutator is made from selected mica plates, with as little bond as possible, and is heated in moulds under a heavy pressure for several hours, the process making it hard and giving it a smooth surface.

When baking the commutator, the temperature is kept between 250 and 300 degrees F., to make certain that the temper of the copper is unchanged, because copper loses ten percent of its hardness above 400 degrees F., and this loss doubles at 500 degrees F.

To prevent the assembled commutator surface from becoming rough by the rising of the individual bars when an increased temperature expands the copper, the assembled commutator is bored at the V's with a slight temperature allowance, making the commutator tight in the arch when the copper has reached its full-load temperature, but without enough pressure to distort the arch of the commutator, thus insuring smooth running under all operating conditions.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1355—**Magnet Brake**—Please tell how the magnet brake on a street car works when the power is off, and why any other series motor won't stop when you short-circuit it when it is running. I have been trying to stop series shunt and compound motors with their own current and I can't do it. I have run the three different kinds up to speed, then I would pull the line switch out and short-circuit it on the motor side by putting a piece of iron across the switch and keeping the controller or starting box on, and I don't even get a spark on the piece of iron. Please tell me how I can stop these motors with their own current. They don't even seem to generate as they are supposed to do; and why don't they generate as they are running up to speed? T. W. S (PENNA.)

The magnet brake on a street car is operated by the current generated by the motors. In order to make a series motor generate it is necessary to reverse the fields. Standard practice is to interchange the fields of two motors to equalize the currents generated. The car is retarded both by the motors acting as generators and by the magnetic action of the brake. Any series motor may be stopped by reversing the fields, and then short-circuiting the motor. To protect the motor, this should be done through a resistance. The best way to stop a shunt or compound motor by its own current is to have the shunt field connected across the line and short-circuit the armature through a resistance. The reason the motor does not generate when short-circuited, as described, is either that the shunt field is not connected across the armature, or that even if connected across the armature, when the armature is short-circuited the field is also short-circuited, so that there is no flux available for generating armature current. If the shunt is connected across the armature, and the motor connected across a fairly high resistance, the motor will generate and be retarded. W. A. C.

1356—**Soldering Armature Leads to Commutator**—Which is the best method of soldering armature leads to the commutator, on large armatures, of 200 and 300 horse-power, 250 volt motors? Is it practical to use an acetylene outfit with a sharp burner, or is it best to use a lead-burning outfit as is used in storage battery work? Please mention any other method and advantages. M. T. C. (HONOLULU)

The oxy-acetylene flame is not practical, for the reason that it is of too high temperature and too concentrated. The hydrogen flame such as is used for lead-burning outfits has the same objections, but in much lesser degree. The best method is to use two copper soldering irons (one being heated while the other is being used) and a charcoal fire or the equivalent in which to heat them. The irons must at all times be kept absolutely clean and well tinned. After the iron is heated it is laid against the joint to be soldered, being held there until sufficient heat has been transmitted from it to the joint, which is indicated by the solder (usually one-half lead—one-half tin) melting. A flux made up of a saturated solution of alcohol and rosin should be applied to the joint before commencing operations, as well as from time to time during the soldering. There are other fluxes which may be used, but many of them are more or less detrimental to the insulation. The advantage of the iron over any flame is that, the heat being lower, it is much easier to protect any insulation in the vicinity and there is less oxydizing action. C. B. A.

1357—**Induction Motor With Uneven Air-Gap**—In No. 1262 you advise a questioner that the rotor of an induction motor being "off center" is unlikely to result in increased heating. I would be pleased to have your opinion regarding the following cases:—On a 250 horse-power, 2200 volt, 450 r.p.m. motor with phase-wound secondary, in an effort to compensate for worn bearings, I shifted the rotor against the rope pull until the air-gap was about one-half as much on one side as on the other. After a few hours' run the motor became so warm on the side of the smaller gap that I was obliged to shut it down and adjust the air-gap to about equal clearance all around, after which the normal temperature was soon restored. At no time did the ammeter read over 60 percent of full-load current. The second case is that of a 35 horse-power, 2200 volt, 720 r.p.m. squirrel-cage motor geared to a triplex mine pump which had been in service about two years and the bearings having become worn sufficiently to let the rotor run very close to the stator on one side. I noticed it was beginning to run warmer on one side than formerly. By shifting the end bells to center the rotor the usual conditions of operation were restored. Would these cases indicate that the local heating was caused by unbalanced magnetic conditions? C. C. C. (ALASKA)

In the case of the first motor there is probably a series connection in the windings of both stator and rotor, and hence no parallels to correct for increased field strength in the pole nearest the small side of the gap. This increased field strength produces local heating at this point due to increased iron loss. The second machine has a squirrel-cage rotor, so there is probably corrective current flowing in the rotor winding tending to check the increased field strength at the point of small gap. This corrective current produces increased heating in the rotor winding, and since the rotor is nearest the stator at the point of smallest gap, heat is transferred to the stator resulting in local heating. In the majority of cases the local heating due to these causes is not excessive and usually goes unnoticed. However, it is possible in certain instances, as noted, that this local heating may become so large as to warrant re-centering the rotor. It is one of the strong points in favor of the induction motor that it operates successfully under a wide range of conditions like this without material change in operating characteristics. A. M. D.

1358—**Water Wheel**—(a) What is meant by "specific speed" of a tangential type water wheel? (b) In tangential water wheel design what are the limits of the ratio that the nozzle diameter must bear to the water wheel diameter? (c) Under average conditions, which would be most suitable to develop 2000 kw under a head of 200 feet;—an impulse type water wheel, or turbine? (d) Which could be expected to develop the highest efficiency, and which unit, generator included, would cost less? R. B. G. (CALIF.)

(a) The expression "specific speed" is not used in connection with tangential type water wheels. The speed of a tangential water wheel is generally 45 percent of the spouting velocity of the water—the speed being taken at the center of the stream line of the jet discharging upon the wheel. (b) The lowest ratio of stream diameter to wheel diameter, which is permissible, is from 10 to 12. (c) For driving a 200 kw generator under 200 feet head, we would recommend an impulse type turbine in place of a tangential wheel. (d) For a turbine having a capacity of, say, 3000 horse-power for direct connection to a 2000 kw generator under 200 feet head, we would recommend a speed of 450 to 600 r.p.m. Such a turbine would develop an efficiency of, say, 81 percent at half load, 86 percent at three-quarter load, 82 percent at maximum full load, whereas, with a tangential wheel the efficiency would be 77 percent at half load, 81 percent at three-quarter load, 80 percent at full load. In order to give 3000 horse-power with tangential wheels under 200 feet head it would be necessary to use four double nozzle wheels on one shaft, and it would not be advisable to go higher than a speed of 180 r.p.m. Under these conditions, the combined cost of turbine and generator would work out somewhat less than the cost of tangential wheels and generators. J. V. K.

1359—B-H Curve—I desire to obtain a B-H curve of the iron and the point at which it is being worked in a 1333 kw transformer, 6600 to 44 000 volts. There are 10 237 cubic inches of iron in the core. I have readings of exciting current and watts for various exciting voltages, the frequency being kept constant at 60 cycles. Will you kindly advise the method of drawing a B-H curve of the iron and locating the point at which same is being worked from the above data?

W. J. M. (ILL.)

The data given with this question are not sufficient for plotting a B-H curve. In addition to this data it is necessary to have the cross-sectional area of the core and the number of turns in the 6600 volt winding. A B-H curve is generally plotted with magnetic flux density, B as ordinates and magnetomotive force, H as abscissa. The flux density is generally expressed in gausses (lines per square centimeter) and the magnetomotive force in gilberts per centimeter length of magnetic field (one ampere turn $= \frac{4\pi}{10}$ gilberts for direct current and $\frac{4\sqrt{2}\pi}{10}$ gilberts for alterating current). Some B-H curves are plotted with B in lines per square inch and H in ampere turns per inch length of magnetic field. If the cross-sectional area of the core and number of turns were known, data for a B-H curve could be computed as follows:—

B (in gausses) $= \frac{E \times 10^8}{4.44 \times f\, A\, N}$, where E = voltage, f = frequency, A = cross-sectional area of core in square centimeters and N = number of turns in the 6600 volt winding. Gilberts per centimeter length $= \frac{4\sqrt{2}\pi\, I\, N\, A}{10\, V}$, where I = amperes and V = volume of iron in cubic centimeters. By means of the above two expressions the flux density (B) and the magnetomotive force (gilberts) can be computed for each of the voltage and corresponding current measurements. The curve should then be plotted on cross-sectional paper with values of B as ordinates and values of gilberts as abscissa. The point on the curve at which the iron is normally being worked is the point corresponding to 6600 volts.

J. F. P.

1360—Transmission Lines—Please advise us present practice of power companies with reference to the use or omission of strain insulators in guy wires used on transmission lines of 22 000 volts or over carried on wood poles. It is not considered best, both from a standpoint of modern construction and safety, to use guy wires without strain insulators in them, employing a long guy rod and getting this as thoroughly grounded as possible. We understand, of course, that on circuits up to, say, 5000 volts, it is the usual practice to install two strain insulators in the guy wires, but one reason for this is to give adequate protection to linemen while working on these circuits while alive by making the guy thoroughly insulated and prevent the possibility of linemen coming in contact with a ground object while working on the energized circuits. Our object is to determine the safety or hazard of guy wires of 22 000 volts or above with reference to the accidental contact of persons or animals with them.

R. L. K. (W. VA.)

We believe the majority of transmission lines of 22 000 volts or over carried on wood poles do not have an insulator in the guy wire. The line insulator should be of sufficient capacity so that the insulation value of the pole need not be considered. An anchor to be of any value must be located far enough beneath the surface of the ground so that the guy wire is much more perfectly grounded than a person standing on the surface, so that there should be very little danger of shocks due to contact with a guy wire. There may be special cases where it is desirable to insulate the guy wire of a transmission line, but, in general, we see no necessity of this precaution.

G. M. E.

1361—If the fields of an alternating-current generator are interchanged while the machine is shut down will the phase relations be correct for paralleling with the bus, or must, with a three-phase unit, two of the alternating-current leads be interchanged?

R. B. G. (CALIF.)

Reversing the field current of an alternating-current generator reverses the phase of the current and voltage, but does not change the phase relations of voltage in the different phases. Therefore, the generator may be paralleled after the field leads have been interchanged by the usual methods of synchronizing. However, if two of the armature leads are interchanged the phase relations of the several generator phases will be changed, which would prevent paralleling.

L. A. B.

1362—Why does an uninsulated steel alternating - current generator slot wedge cause trouble by heating? If a small amount of insulation is placed between the laminations and the wedge no heating will occur; hence it seems to me that the trouble must be caused by the wedge short-circuiting the laminations.

R. B. G. (CALIF.)

Placing an uninsulated steel slot wedge in an armature short-circuits the laminations and provides a path of low resistance for the flow of the induced eddy currents. This defeats the purpose of laminating the armature iron in order to insure high resistance in the path of the eddy currents. Provided the wedge is insulated from the iron the loss due to short-circuiting the armature laminations is eliminated, but there is still a loss present caused by the iron loss in the wedge itself. This loss is dependent on the design of the wedge, but is much less than the total loss caused by the combination of the loss in the wedge and the loss due to the short-circuiting of the laminations by the wedge.

R. K.

1363 — Paralleling Alternators — Assuming that four 2000 kw generators are normally operated in parallel, is it permissible to parallel them by bringing them to normal speed, closing their respective field and alternating-current switches, and building up the field uniformly on each by the exciter field rheostat? It must be understood that there is no current on the bus when the generators are connected thereto. Will the above method of operation subject the generators to greater strains than paralleling them in the usual manner, sometimes a few degrees out of phase?

R. B. G. (CALIF.)

The generators will parallel by the above method if the fields are uniformly and slowly built up after the line switches are closed. The maximum cross current between the machines will occur when the generator voltages are in phase and in the same directions. This current is approximately equal to the sustained short-circuit current of one of the generators. However, this maximum value of cross current will only last for a short period, as the torque tending to pull the generators in voltage opposition with each other is a maximum when the cross current between generators is a maximum. This method of paralleling is more severe than where the generators are synchronized within a few degrees before paralleling.

L. A. B.

1364 — Rewinding A.C. Motors — I have an article clipped from the JOURNAL of May, 1911, on "Winding Dynamo-Electric Machine XII," by Mr. M. W. Bartmess. This has always been a very interesting and helpful article for me. Lately I have been very busy converting alternating-current machines from 110 or 220 volts, two-phase to three-phase, by rewinding entirely, as reconnected machines have not proved very satisfactory; also 2300 volt machines. Some of these machines are small and some as large as 150 horse-power. I would like very much to know Mr Bartmess' method of figuring sizes of wire, turns necessary, number of coils, etc. I realize, of course, that some machines cannot be readily changed and that on some I may be handicapped on account of slot sizes, etc., but I would like to know what ought to be used if the design were worked out for a new machine, and then possibly I can make a suitable and satisfactory change to suit each special condition.

G. H. T. (TEXAS)

(a) A two-phase motor which is suitable for reconnection for three-phase, if reconnected, should be operated on an equivalent three-phase voltage equal to approximately 125 percent the two-phase voltage. That is, if a 220 volt, two-phase motor is connected in three-phase star it should be operated on 272 volts, if connected in delta, on 157 volts. Since a change in voltage is obtained by a corresponding change in number of effective turns (e. g., connecting in parallel for half voltage) it is evident that a 220 volt, three-phase motor should have 81 percent ($220 \div 272$) of the number of turns of a 220 volt, two-phase motor. Assuming the same resulting efficiency and power-factor, the three-phase current will be $2 \div \sqrt{3}$ times the two-phase current for the same load, or 15 percent greater. Hence to keep the same current density it would be necessary to increase the section of the copper 15 percent. As this is not practicable except in some cases of strap windings, and also since 81 percent of the number of turns of the next size larger wire will require approximately the same slot space as the original coil, it is common practice to use one size larger wire for a three-phase motor than is used for the corresponding two-phase motor. One size larger wire has 26 percent larger section and, other features being equal, should give a slightly cooler motor with somewhat increased torques. The various features to be taken into account in laying out a winding for a

new machine are too numerous to be considered in the Question Box. It is best to assume that the designer in laying out the motor in question has taken these points into consideration, and to use the results as embodied in the existing winding as a basis for the new winding. Refer also to Mr. A. M. Dudley's article, "Reconnecting Induction Motors," in the JOURNAL for February, 1916. M. W. B.

1365—Kind of Current—Where direct and alternating current both are used in a building, what test can I make to distinguish these currents? T. S. F. (ILL.)

Two simple methods of determining whether the wires carry alternating or direct current are as follows:—1—A direct-current, permanent magnet type voltmeter will indicate the voltage on direct current, but on alternating current only a slight vibration of the needle will be noted. (Care should be taken to put a suitable multiplier in series with the voltmeter if the line voltage is greater than the full scale reading of the instrument). 2—If an incandescent carbon lamp, the filament of which is free to vibrate, is placed across the line (in series with the necessary resistance, or on the secondary of a transformer if the line voltage is greater than that for which the lamp was manufactured), a good size permanent horseshoe magnet will cause the filament to be deflected to one side or the other in the case of direct current, while the filament will vibrate at a high frequency if the current through the filament is alternating. A. W. P.

1366—Flood Lighting—Please describe the method of illumination known as flood lighting. R.B.G. (CALIF.)

Flood lighting consists in lighting the exterior of a building, of certain architectural features, of a billboard, or other object by means of searchlights. The most common method at the present time is to use Mazda C lamps with a very concentrating type of mirrored reflector. By locating these searchlights suitably the architectural features of a building may be brought out prominently at night without bringing the sources of illumination into the ordinary line of vision. C. R. R.

1367—Adjustable-Speed Motor—On what part of the magnetization curve is an adjustable-speed motor worked that has a speed adjustment from 400 to 1200 r.p.m., and what would be its regulation on high speed? A. H. D. (DIST. OF COL.)

An adjustable-speed motor having a speed variation from 400 to 1200 r.p.m. when operating at minimum speed is worked at or slightly above the knee or sharpest bend of the magnetization curve. At maximum speed it operates with one-third the maximum speed flux, that is, on the straight part of the magnetization curve. The regulation of the motor at high speed should be 5 to 15 percent. See article in this issue by Mr. H. L. Smith. R. L. W.

1368—Circulating Current—What is the magnitude of the circulating currents in a bank of identical transformers, Y-delta and delta-delta? What is the magnitude of the difference in potential found on opening one corner of a delta bank of identical transformers both delta-delta and Y-delta (i. e., opening through a high-resistance voltmeter)? M. S. G. (CALIF.)

The current that circulates in a three-phase bank of transformers with identical characteristics, with balanced three-phase sine wave voltage impressed, is principally the triple frequency part of the magnetizing current that is necessary to produce a sine wave voltage. A small amount of ninth and fifteenth harmonic currents will also circulate, but these are small compared with the third. The magnitude of the necessary third harmonic component of magnetizing current to produce a sine wave voltage varies considerably in different sizes and different designs of transformers. It probably never exceeds three percent of the normal full-load current of one unit of the bank. If the bank of transformers is connected star-delta, all of the third harmonic current will circulate in the delta side, and if the bank is magnetized on the star-connected side, an ammeter placed in the corner of the delta will indicate the magnitude of the circulating current. If a high-resistance voltmeter be connected in the corner of the delta then the required amount of third harmonic current cannot flow, and the voltmeter will indicate approximately the sum of the third harmonic voltages in the three phases, which are due to the absence of the necessary third harmonic component of magnetizing current. The sum of these third harmonic voltages should not exceed 50 percent of the normal phase voltage. If the bank is magnetized on the delta side, an ammeter connected in the corner of the delta will indicate approximately the same current as when the bank was magnetized from the star side. A high-resistance voltmeter connected in the corner of the delta when the bank is magnetized on the delta side virtually converts the connection into an open delta or V on the primary side. For this connection a large part of the third harmonic current is drawn from the line and the voltmeter will indicate a considerably less voltage than when the bank was magnetized on the star side. If the bank of transformers is connected delta-delta, then part of the third harmonic current will circulate in the primary and part in the secondary sides of the bank. Therefore, in order to measure the magnitude of the circulating current, two ammeters should be used,—one connected in a corner of the primary and one in a corner of the secondary. The sum of these two readings, after taking the ratio of transformation into account, should be approximately the same as for the star-delta bank. A voltmeter placed in a corner of one side of a delta-delta connected bank will indicate approximately zero voltage, as the third harmonic current will then all circulate in the delta into which no voltmeter has been connected. If two voltmeters are used, one in the primary and one in the secondary, then the voltmeter readings should be approximately the same as for the star-delta connected bank when magnetized on the delta side. J. F. P.

1369—Rectifier Trouble—I have a Wesinghouse vibrating rectifier and have a little trouble with the charging current. The rectifier will deliver eight amperes for a short time and then will drop back to about three, and then if we turn the current off, and turn it back on, it will not deliver any current. This charging current cannot be depended upon to charge the battery, because part of the time it has eight amperes and part of the time is not anything. Will you please explain what can be done to remedy the trouble? E. E. M. (MICH.)

The vibrating rectifier is a device which depends for proper operation on the correct timing of the vibrating armature with reference to the applied alternating voltage. The control springs are so adjusted as to make the normal natural frequency of the armature somewhat below that of the line on which the outfit is to be applied. In case the adjustment is disturbed, or the parts wear sufficiently to change the armature frequency, the vibration is liable to become erratic and the current delivered on the direct-current side may be decreased in value or even reversed. The cure for a condition of this sort is the readjustment of the control springs and contacts, which may be done as follows:—Loosen the clamping screws in the four binding posts on which the stationary contacts and fibre-tipped screws are mounted. After turning back the contact screws until considerable separation exists, advance the fibre-tipped screws in such a manner as just to make contact with the control springs, keeping the armature parallel to the front edge of the slate. Turn each of these screws approximately three-quarters of a turn further. See that the separation between the alternating-current magnets and the ends of the armature is about one-eighth of an inch on each side. Tighten the clamping screws to lock the fibre-tipped screws. Advance the contact screws until contact is just made, and then turn back approximately one-quarter turn. The adjustment is now approximately correct, and it is necessary to make only minor adjustments to make the operation entirely satisfactory. The adjustments which may be required are slight changes in the contact separation and changes in the position of the slide on the adjustable resistor. See also article on "The Vibrating Rectifier," by Mr. Q. A. Brackett, in the JOURNAL for December, 1912, p. 1094. A. L. A.

1370—Charging Current—If a transmission line operated at 150 kilovolts requires a charging capacity of 6000 k.v.a., what charging k.v.a. would be necessary if the voltage were changed to 60 kv? R. B. G. (CALIF.)

The charging current of a line varies directly as the impressed voltage or $I_c = 2\pi f E_c C$. In the above we understand that line spacing will remain unchanged, so that the only variable will be E_c or impressed voltage. The charging k.v.a. will vary as the square of the voltage, so that for 60 kv the charging k.v.a. will be 950 for a line having 6000 k.v.a. at 150 kv. F. C. H.

1371 — Transformer Power-Factor—What is the no-load power-factor of an average 2000 k.v.a. 2200/88 000 volt transformer? R. B. G. (CALIF.)

The average no-load power-factor of such a transformer is approximately 15 to 20 percent, lagging, and for 25 cycles approximately 10 to 15 percent, lagging. J. F. P.

FINANCIAL SECTION

HOLDING COMPANY SECURITIES

Some time ago an authority on public utility investments estimated that, of the outstanding securities of operating companies in the electric light and power industry, in excess of 82 percent were owned by holding companies, while more than 66 percent of the securities of operating gas companies were held by holding companies, with 81 percent of the securities of electric street and interurban railways also owned by the holding corporations of this country. Thus of more than $8 000 000 000 of securities of the corporations operating electric light and power, natural and artificial gas and electric street and interurban railways of the country more than $6 240 000 000, or in excess of 78 percent, are owned by the modern public utility holding companies. There are approximately 150 of these holding companies, the securities of which, previous to the outbreak of the present war, were being eagerly purchased by European investors as well as by those of this country. Since the outbreak of the war hundreds of millions of dollars of these securities have been returned to this country, but the market has absorbed them without great shock, and today the securities of the public utility holding companies of the country are more widely held by the investors of the United States than ever before.

It may appear somewhat strange, but it is a fact, nevertheless, that it was the organization of the holding company which has made possible the wide distribution and the great gain in favor of electric light and power and other public utility securities in the last few years. So far as the local operating companies were concerned, their securities were usually closely held, and if distributed at all were held only by men in the immediate vicinity of the property. In the case of the holding company, the securities, representing a light and power plant in the north, a gas plant in the south, a hydro-electric development in the west and a street or interurban railway in the middle west, may be held by men in sections of the country as widely separated as the properties on which they are issued. The holder of these securities is interested in the progress of every locality in which each of the properties of the holding company is located, and the wide distribution of the securities of these corporations has done much towards bringing in closer relationship the various sections of the country from an investing viewpoint.

The holding corporation for public utility properties should not be confused with the holding companies which have gained such unenviable notoriety in connection with steam railroads and industrial financing. The utility holding corporation movement came about for an entirely different reason, and has grown to its present proportions in the public utility field because of the fact that through it plans could be carried out for the betterment of service and for economy of financing which could be obtained in no other way. The public utility holding company in the first instance was an attempt to apply the law of averages to public utility operation and financing based on the theory that business conditions could not be depressed at the same time in all localities in the country. It was figured that by securing a diversity of location of the utility properties, through their ownership by a holding company, a stability of earning power could be secured and that while, as an example, business conditions might be bad in the localities in the south where properties were located, the reverse would be true with the northern properties; or that while earnings with western utilities might fall behind, the operated properties in the eastern section of the country would increase their earnings at a rate which would make up for the decrease in the west.

Experience has proved this theory to be sound, and in practice it has worked as it was anticipated it would. As an instance to the point, in 1914 conditions were bad in the southern states and utility earnings in that section were not up to the standard, yet a large utility holding company which owned properties in that section reported an average rate of gain in its total earnings for the year. This was because the company also owned a number of properties in Wisconsin, Minnesota, the Dakotas and other northern states, and the increased gains at these properties more than offset the decrease in the southern properties. In fact, in the purchase of the preferred and common stocks of public utility holding companies, if properly organized and with operated properties well diversified, the investor obtains in effect a diversity of investment which he would find it difficult to secure in any other way.

With the great expansion in business of utility companies in the last fifteen years, it was found that, except where the properties were of magnitude, it was difficult to do financing on any reasonable terms, because of the comparatively small issues of securities to be made by any one property, and also because of the limited market for such securities. With the combination of a large number of these small properties, the holding company could make a blanket issue of securities large enough, not only to attract the large banking houses which would buy them on favorable terms for distribution to the investor, but also to enable a good market to be made for the issues. But more than all other factors was *the opportunity given for the centralization and standardization of operation of utility properties and the giving, even to the smallest property, the benefit of high-class engineering and operating supervision. This was made possible through the organization by the holding companies of engineering and operating departments composed of the best talent obtainable.* In this manner it is possible for the holding company to give to the utility located in a town of 10 000 people as high a class of engineering and operating supervision as is rendered the utility located in the largest city of the country. As a separately operated property the small utility would find the cost of such expert advice and assistance far beyond its means, but as a member of the operated group of the public utility holding company this expert supervision is given it as a right. In addition, methods of operation, accounting, merchandising and other factors in the life of the companies are standardized and, so far as possible, equipments at the various properties are also of one standard. Many economies are inaugurated in operation and financing, and at the same time all endeavors are turned towards giving the best possible service to each community.

It will be found, if an analysis is made of the advance in operating methods and earning power of the utility companies of the country over the last ten years, that the properties operated under centralized holding company management have been the leaders in substantially every factor in this advance. They were the first to take up the systematic campaign for new business; they were the ones to push the sale of the lamp socket household electric appliances, and today they are leading in almost every line of the utility industry.

Of the holding companies operating properties along the lines of modern financing, engineering and operating practice, American Light & Traction Company was practically the first. There were other holding companies with large investments in the securities of individual properties previous to that time, but they were almost wholly financing companies, and the operation of the separate properties controlled by them was

FINANCIAL SECTION

not centralized, each property being operated individually. The success of American Light & Traction Company led to the organization of a number of other corporations on the same lines. Among those which have been most successful are Cities Service Company, organized by Henry L. Doherty & Co.; American Gas & Electric Company, controlled by General Electric interests; Northern States Power Company, organized by H. M. Byllesby & Co.; United Light & Railways Company, Middle West Utilities Company, Public Service Corporation of New Jersey, United Gas Improvement Company, North American Company, American Power & Light and other companies under control of the Electric Bond & Share Company; Commonwealth Power, Railway & Light Company; Ohio Cities Gas, United Gas & Electric Corporation, and a number of others. With almost all of these companies the preferred stocks are good investment issues and the common stock possesses most attractive speculative possibilities. American Light & Traction has sold above $400 for the $100 shares, American Gas & Electric at $145 for the $50 shares, Cities Service Company at $360 for the $100 shares, and in the case of the others the stocks, while not having had these extreme advances, have made material progress in market value above their price at time of issue. Where the collateral trust bonds of these companies, if such have been issued, are based on first mortgage bonds of the underlying properties, they enjoy a high rating as investments, while where they are based on the stocks of the operated properties they are rated as fair investments, but, of course, not of a grade with those which have bonds as their collateral. There is a steadily widening market for the securities of these utility holding companies, and in making up a list of utility issues, either for investment or for more speculative possibilities, these securities should not be overlooked.

The centralization of management and financing and the standardization of operating methods and of equipment are being reflected in the steadily growing earning power of these syndicate-controlled properties, and it has been due to them more than to any other factor in the electric light and power industry that such rapid progress has been, and is being, made in this industry.

ELECTRICAL EARNINGS IN FIRST HALF OF 1916

Predictions made soon after the opening of the current year that earnings of the electrical public utilities of the country would make new high records in 1916 are being borne out by the reports so far received for the first six months of the year. The rate of gain in earnings is the highest in the history of the electrical industry, and it must be remembered that this rate of gain is predicated, not as in the case of almost all other industries of the country on a heavy falling off in earnings in the first half of 1915, but that with the electric service industry the first half of 1915 showed a fair rate of gain over the first six months of 1914. The effect of the depressed business conditions of the first half of 1915 in the case of electrical utilities, as a whole, was to decrease the rate of gain in revenues, but at the same time their earnings were above those for the first half of the preceding year. It now begins to appear that the estimate of $400 000 000 for total revenues of the electric light and power industry for 1916 will be too low, and that this estimate will have to be revised upwards if earnings for the first half of the year may be taken as a basis for the full year. While figures for the entire industry for the first half have not been received, enough have been received to indicate that in the first six months of 1916 total revenues of the electric light and power industry of the country were well above $200 000 000.

Some of the companies which are now reporting show phenomenal gains over the first half of 1915. Virginia Railway & Power Company reported 11 percent gain in gross and 12.6 percent gain in net; Louisville Gas & Electric Company, 12 percent gain in gross and 23.5 percent gain in net; Cleveland Electric Illuminating Company made a gain of 9 percent in gross and 4 percent in net; Wisconsin Edison Company, Incorporated, reported 10.7 percent gain in gross and 11.6 percent in net; Public Service Corporation of New Jersey, the largest public utility in total earnings of any in the country, reported 13.3 percent gain in gross and more than 33 percent gain in surplus. Western States Gas & Electric Company reported 5 percent increase in gross and 4 percent increase in net; Pacific Gas & Electric Company, despite the loss of the revenues from the Panama-Pacific Exposition, reported an increase of 15 percent in gross, with a small decrease in net, owing to much larger maintenance and depreciation charges; Duquesne Light Company, of Pittsburgh, increased its gross 17 percent and its net 15 percent; Great Western Power Company, of California, made a gain of 24.4 percent in gross and 10.5 percent in net; Commonwealth Power, Railway & Light Company, covering a large part of Michigan, with properties in Ohio, Indiana, Kentucky and Illinois, reported an increase of 18.3 percent in gross and of 18.2 percent in net, while Consumers Power Company, of Michigan, made gains of 24 percent in gross and of 18.6 percent in net.

The combined earnings of the utility properties operated under management of H. M. Byllesby & Co., including plants in about fifteen states, showed gains of 9 percent in gross and of 11 percent in net; Northern States Power Company gross increased 16.4 percent for the first six months of 1916 over the corresponding period of 1915, while net increased 19.3 percent; Appalachian Power Company gross gained 28 percent and net 56 percent, while gross of Republic Railway & Light Company gained 32.7 percent and net 40.3 percent; Pacific Light & Power Corporation reported a gain of 13 percent in gross and 12.5 percent in net, and gross of Twin City Rapid Transit is running 10 percent ahead of 1915; American Power & Light Company gross gained 7 percent and net 10 percent, and United Light & Railways Company gross increased 10 percent and net 12 percent; Utah Securities Corporation gross was 14 percent ahead of the first six months of 1915, and net gained 25 percent; United Gas & Electric Corporation gross increased 10 percent and net 15 percent, while combined gross of American Cities Company is gaining at a rate of 10 percent and net at about the same amount.

Advance estimates from other leading electric light and power companies indicate that they are sharing equally as largely in the prosperity of the industry, and there is no doubt that both gross and net revenues for 1916 of the companies will be by far the highest of any year in the history of the central station industry. The steadily advancing prices of the securities of these companies show what a factor these large gains in earnings are in the market position of their stocks and bonds and, with a continuance of similar gains over the last half of the current year, it seems certain that in addition to the great gains being made in their revenues there will be recorded almost equally as large percentages in the market quotations of their securities.

WEST PENN TRACTION

West Penn Traction makes a favorable statement for the month of June and the first half of the year. In June gross earnings increased 22 percent, but on account of higher operating expenses and charges only a small amount of this increase was saved for the surplus. For the six months surplus amounted to $450 081, an increase of $207 226. This surplus was at the rate of 58 percent per annum on the $1 625 000 West Penn Traction 6 percent preferred stock and, after allowing for the dividends on this stock, the balance was at the rate of 12.4 percent on the $6 500 000 preferred stock of the West Penn Traction & Water Power Company, or at the rate of 6 percent on this latter stock and 2 percent on the common stock of the same company. It is understood that the West Penn Traction Company charged off $150 000 more for depreciation in the first six months this year than last, the charge being covered in operating expenses. The latest statement follows:—

	June, 1916	Increase
Gross earnings, all sources	$514 013	$95 576
Operating expenses	253 577	66 889
Net earnings	260 435	25 987
Taxes	22 066	3 106
Balance	238 369	25 880
Fixed charges and dividends of subsidiary companies	173 392	20 764
Surplus earnings	64 976	5 116
Six months ended June 30, 1916:—		
Gross earnings, all sources	$2 957 040	$569 378
Operating expenses	1 366 082	242 204
Net earnings	1 590 958	327 173
Taxes	130 398	16 637
Balance	1 460 550	310 536
Fixed charges and dividends of subsidiary companies	1 010 477	103 309
Surplus earnings	450 081	207 226

PERSONALS

Mr. W. R. Armstrong, general manager and chief engineer of the Salt Lake & Utah Railroad, has been appointed engineer maintenance of way of the Union Pacific Railroad, with offices at Omaha. Mr. Armstrong went with the Salt Lake & Utah in 1913. A description of this line and others in Utah, as prepared by him, was published in the JOURNAL for October, 1915.

Mr. G. A. Trube, managing director of the French Westinghouse Company, has recently been appointed export manager of the Westinghouse Air Brake Company and Westinghouse Traction Brake Company, with headquarters at Pittsburgh, Pa. Mr. Trube has had a wide foreign experience, having been associated with the Westinghouse Air Brake Company and the Westinghouse Electric interests for many years both in this country and abroad. He went to England in 1900, where he made his headquarters until 1912, when he was transferred to Paris.

Mr. J. E. Saunders, formerly electrical engineer of the Union Switch & Signal Company, Swissvale, Pa., has been appointed assistant chief engineer. Mr. C. R. Beall succeeds Mr. Saunders to the position of electrical engineer. Mr. W. P. Neubert has been appointed mechanical engineer. All appointments effective August 1.

Mr. E. S. Zuck, of the general engineering department of the Westinghouse Electric & Mfg. Company, East Pittsburgh, has resigned to enter the new business department of the Bridgeton Electric Company, at Bridgeton, N. J., which is operated by the American Railways Company.

Mr. Axel J. Stahl, of Stockholm, Sweden, has recently incorporated an organization to be known as A. J. Stahl & Co. to carry on general engineering work. Mr. Stahl was formerly with the General Electric Company, of Schenectady, and later with the British Thompson-Houston Company, Limited, and more recently was chief electrical engineer for Graham Bros. in Stockholm.

Mr. K. H. Rohrbaugh, formerly publicity representative of the Westinghouse Electric & Mfg. Company at the Philadelphia office, has been transferred to East Pittsburgh to be associated with the Dealers' Help Division of the Publicity Department.

Mr. J. S. Hobson, general sales manager of the Union Switch & Signal Company, has been appointed western manager in charge of the Chicago, St. Louis and San Francisco offices, with headquarters in Chicago.

Mr. B. O. Austin, formerly of the engineering department of the Westinghouse Electric & Mfg. Company, and more recently with Gilbert C. White, consulting engineer, Durham, N. C., has opened a consulting engineering office at Charlotte, N. C.

Mr. C. E. Denney, assistant general sales manager of the Union Switch & Signal Company, has been appointed assistant to president, with headquarters at Swissvale, Pa.

Mr. Edward P. Burch, consulting engineer of Minneapolis, Minn., has been appointed to represent the city of Cleveland in the valuation of the Cleveland Electric Illumination Company.

Mr. C. E. Thompson has entered the employ of Westinghouse Electric & Mfg. Company's San Francisco office as treasurer's accounting representative.

Mr. F. M. Murphy, sales manager of the Bates Expanded Steel Truss Company, Chicago, Ill., has resigned to enter other business.

Mr. L. G. Shepard, electrical engineer of the Federal Sign System (Electric) Company, of Chicago, Ill., has resigned to enter the employ of the Milwaukee Western Fuel Company, Milwaukee, Wis.

The Pennsylvania Electric Association, State Branch of the N.E.L.A., will hold its ninth annual convention at Eagles Mere, Pa., September 5 to 9, 1916.

TRADE NOTES

The Morse Chain Company, of Ithaca, N. Y., has increased its stock from $400 000 to $1 500 000 for the purpose of extending its equipment in buildings, etc. This company started in business at Trumansburg, N. Y., in 1904. In 1906 it moved to a new factory in Ithaca twice as large as the former one. In 1912 it again became necessary to enlarge and the floor space was more than doubled. Present plans contemplate again doubling the size of the plant. When these buildings are completed the Morse Chain Company will have a total floor space of approximately seven acres, devoted exclusively to the manufacture of Morse rocker-joint power transmission.

The S K F Ball-Bearing Company, of Hartford, Conn., has recently published a very elaborate handbook entitled "Better Electric Motors." This contains not only some unusual descriptive matter, handsomely illustrated, but also goes into details as to comparative efficiencies of different types of bearings, savings in lubrication, bearing sizes and rules for completing and mounting ball-bearings. Some of the topics of special interest are "How Maintenance Charges Are Reduced 60 Percent" and "Motor Lengths Shortened 10 to 27 Percent." This book has been copyrighted by the S K F Ball-Bearing Company, who will gladly send copies to those interested on request.

The Union Switch & Signal Company, General Railway Signal Company, Federal Signal Company and Hall Switch & Signal Company have entered into a cross-licensing agreement under the several patents, applications for patents and inventions owned by them respectively, copies of which agreement have been filed with the Department of Justice and the Federal Trade Commission. The purpose of this agreement is to end patent litigation between the several companies and to put each in a position to make the safest and most effective types of signaling and interlocking systems and apparatus.

The Westinghouse Lamp Company is distributing a small booklet entitled "Cash for Your Ideas," describing a scheme which it has evolved to secure interesting stories of salesmen's experiences in the selling of incandescent lamps. Prizes are offered for exceptional contributions. A copy of this booklet can be obtained by addressing the company at 165 Broadway, New York City.

The Spray Engineering Company, 93 Federal street, Boston, Mass., has recently published its Bulletin No. 201, which describes the "Spraco" system for cooling condensing water. Numerous interesting illustrations of important installations are shown, with data as to actual results obtained. Detailed description is also given of the design of the nozzles used and of the arrangement of sprays. In this system the hot water is cooled by spraying it into the air, so that when it falls into the cooling pond or basin its temperature is sufficiently reduced to be used over again. A power plant can thus be located convenient to a fuel supply or distributing center without considering the condensing water supply. Where space is limited this system can also be installed on the roofs of buildings. Copies of this publication will be sent on request.

The Pelton Water Wheel Company, of San Francisco, has recently published its Bulletin No. 9, which describes and illustrates its Pelton-Doble centrifugal pumps. These pumps have been a product of this company for over 10 years and have been built in many designs for a great variety of applications. Copies of this bulletin will be sent on request.

The Electric Storage Battery Company, of Philadelphia, has just published its Bulletin No. 159 on "Storage Battery Mine and Industrial Locomotives." In addition to details regarding this type of battery, numerous illustrations are shown of typical mine locomotive installations. Copies of this bulletin will be sent on request.

The industrial department is the new name for the commercial sales division of the Hyatt Roller Bearing Company, Newark, N. J. This department is located in Newark with the factory. The time is coming fast when all through the industrial world the truth of the anti-friction proposition will be accepted just as it has been accepted by the automobile builder. And for that reason the industrial department of the Hyatt Roller Bearing Company is preparing to meet conditions. Already the question that a great many manufacturers are deciding in regard to the bearing situation is what kind of anti-friction bearing is the best for the line shaft boxes, industrial trucks, mine cars, machine tools, electric motors, cement machinery, cranes and trolleys, textile machinery, blowers and fans and conveyors. These manufacturers know that the anti-friction bearing must be a necessary part of these products in order to assure maximum efficiency. Probably never has any industry done as much to revolutionize manufacturing as did the automobile industry. And during this revolutionization the importance of the anti-friction

bearing was brought forth. The motor car as it is known today would not be practical were it not for anti-friction bearings. What the anti-friction bearing did for the automobile industry it can do for the other lines of manufacture. No piece of machinery that requires revolving parts is performing its best work unless revolving parts turn without unnecessary friction.

HUBBELL FOCUSING, DISTRIBUTING AND INTENSIVE REFLECTORS

Three new Hubbell reflectors have just been placed on the market. They are classified as focusing, distributing and intensive. Fig. 1 shows the focusing type for 60 watt lamps; Fig. 2, the distributing type for 100 watt lamps; Fig. 3, the intensive type for 100 watt lamps.

FIG. 1

FIG. 2

FIG. 3

FOCUSING, DISTRIBUTING AND INTENSIVE REFLECTORS

Intensive reflectors are primarily designed for the lighting of large areas, though they may be used to advantage in illuminating a group of machines by centrally suspending them from drop cords, thus reducing the distance between the unit and the floor and intensifying the light within the required area.

The focusing type is recommended for localized illumination of high intensity over a small area. The smaller units are particularly adapted for bench work where small articles are assembled or where vises are used.

The distributing type, as its name implies, is intended for general illumination in factories or warehouses.

All of these reflectors are equipped with the standard Hubbell contractile collar holder, making the use of a separate shade holder unnecessary. The maker is Harvey Hubbell, Inc., Bridgeport, Conn.

A.E.R.A. CONVENTION

The 1916 convention of the American Electric Railway Association is to be held on Young's Million-Dollar Pier, Atlantic City, October 9-13. It is expected that there will be an unusually large attendance at this convention.

NEW BOOKS

"Business Psychology"—Hugo Munsterberg. 296 pages, flexible leather binding. Published by La Salle Extension University, Chicago.

In this book Professor Munsterberg attempts to give a working understanding of psychology to the modern business man. Those who fancy that business affairs should be treated in the snappy way of ordinary business literature will be disappointed in this work. Such gingery talks as are usually offered to business men are entertaining and sometimes stimulating, but a thorough understanding of business conditions can be gained only by serious study. The first half of the volume hardly speaks of buying, selling, advertising and selecting workers. It is believed that this apparently unpractical study is needed if the latter sections of the discussions are not to hang in the air. Among some of the final chapters are those on vocational fitness, individual mental traits, selection of individuals and mental tests.

"Standards for Electric Service"—Circular No. 56. Issued by the Bureau of Standards, Department of Commerce, Washington, D. C.

In the preparation of this circular the bureau had the very cordial and helpful assistance of committees representing the N.E.L.A. and A.E.I. companies. The joint meter committee of these associations gave the bureau much time, and through subcommittees, criticised and made suggestions on various parts of the circular, both in its manuscript form and in galley and page proof. Finally 75 or more copies in final page proof were submitted to Mr. John Lieb, of the New York Edison Company, who, acting for the associations above mentioned and the A.I.E.E., distributed these copies rather widely. A final conference was held with a committee representing the operators, who thus had opportunity to go over the circular in proof, and the bureau believes the circular has the approval of the industry as represented by these associations. In addition to this very cordial co-operation, the public service commissions throughout the country were consulted. In fact, nearly every commission was visited by representatives of the bureau during the course of preparation of the circular, and valuable comments and criticisms received. During the time the circular was in preparation, service rules were adopted by half a dozen or more states, among them Connecticut, Illinois, Maryland, New Hampshire, Oregon, Pennsylvania and West Virginia, and in all cases the bureau, at the request of the commission, made written suggestions on the proposed rules, and in a number of instances attended the public hearings. It is believed, therefore, that the proposals made in the circular represent the very best "accepted good practice" in commission regulations, and that the circular, as a whole, will be of interest and value to public service commissions, to central station operators and to municipal boards and commissions everywhere. Chapter I discusses in some detail the factors entering into adequate and safe electric service. Chapter II is essentially a specification for the acceptance of types of watthour meters by public service commissions and is a revision of the corresponding section of the "Meter Code." This revision was made with the co-operation and assistance of the joint meter committee, under whose auspices the "Code" was developed. Chapter IV is an exhaustive compilation of all public service commission rules now in force, while chapters V and VII are proposed commission rules and city ordinances for regulating electric service. Interesting tabulations of various kinds are given in appendixes, in addition to extracts from public service commission laws. Copies of this circular may be obtained through the director of the Bureau of Standards, Mr. S. W. Stratton.

THE VAUGHN FLOW METER

The Spray Engineering Company has recently placed on the market a simple and efficient instrument for indicating the flow of liquids in pipes, under the designs and patents of Mr. J. F. Vaughn This meter is especially applicable to water-cooled transformers, boiler supply water, lubricating refrigerating and heating systems, etc. The instrument consists of a cylindrical chamber, including a slotted tube through which the liquid must pass. Enclosed in this tube is a piston which, as the liquid passes through, is raised until the exposed area of the slots is sufficient to allow the flow of the liquid. The index at the top indicates directly the flow of liquid in gallons per minute. An electrical device can also be used, if desired, to signal, by lamp or bell, when the amount of liquid flow exceeds or falls below a prearranged amount. The loss of head in operating this instrument is practically negligible, and the indicator has been found to be quite accurate under tests. Circulars and further information may be obtained by addressing the manufacturers, The Spray Engineering Company, 93 Federal street, Boston, Mass.

THE ELECTRIC JOURNAL

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The Trend of Electric Power Developments We are now witnessing the beginning of a notable and, it is believed, an epoch-making change in the use of electric power, due largely to the wonderful development and economy of the steam turbine and its direct-connected electric generator, and the remarkably flexible, efficient and easy distribution of electric power. The manufacturers of steam turbines of large size are having their extreme capacity for production of such machines taxed to the limit. This very large demand is caused by the great improvement in economy of these large machines over those of smaller size, causing the replacing of small by large turbines, and also a great demand for more electrical power on account of the present large expansion in industrial requirements. Both of these causes are bringing about a rapid enlargement of central power stations.

The capacity of large central stations to handle service requiring power in large and irregular amounts, which is impracticable in smaller stations, is another condition which is still further adding to the demand upon such large central stations and causing more large steam turbines to be built. Thus fluctuating loads, too large for a small station, may be entirely practicable when the station capacity is amply large. Power requirements of electrified steam railroads and rolling mill electrifications, for example, with their sudden changes in load and large motor units, are readily handled only by a large power station.

In addition to the increased efficiency due to more economical units and the increased capacity from concentration of a number of very large generators in one central station, improvement in load factor has also resulted. This comes from the increase in the diversity of service, making it possible to deliver a much greater total output with a given peak capacity. Improvements in mechanical stokers, superheaters, economizers and other adjuncts to the boiler plant of large electric stations also add to the economy of electric current production in these large power plants.

The development and use of protecting and safeguarding apparatus is greatly stimulated and, in fact, made necessary by the growth in size of electric power stations. Thus a short-circuit on a 100 000 kilowatt power station may bring about conditions so severe as to be beyond the limitations of any known switching or circuit-breaking apparatus. In order to prevent such occurrences, protective apparatus, normally inert, but which comes into action when danger threatens, has been developed and is being continually improved.

What does this great development in the efficiency of the steam turbine and increased capacity of the large central station portend?

First—As already stated, a rapid increase in the use of electricity from these large and economical power stations in all kinds of industry requiring mechanical power.

Second—The rapid development of the use of electricity in reducing certain metals such as aluminum, etc., from their ores, and the refining of metals such as copper, as well as the use of electricity in tempering, welding and forging operations, and also in the melting of iron and steel.

Third—The steady growth, already rapid, of the great electrochemical industry, including many kinds of products, among the largest, in point of consumption of electricity, being the fixation of the nitrogen in the air, producing valuable fertilizer, etc.

Fourth—The electrification of steam railways. The tendency is towards standardization of transmission and contact systems. This development is slow at present but, with return to normal prices for materials and labor, will progress rapidly.

Fifth—The electric propulsion of steamships. Beginning with the special and exacting requirements for cruising and maneuvering of naval vessels, the propulsion by electric power is now found to be also advantageous in very large vessels for the merchant marine. This results from the much greater steam economy and greatly reduced weight of the high-speed turbine directly connected to an electric generator, compared with either reciprocating engines or turbines directly connected to the screw propellers. The boilers, steam turbines and generators here constitute a power plant on shipboard which can be placed in the most suitable location, regardless of the location of shafts to screw propellers, as these may readily be fitted with adequate electric motors wherever located.

The trend of electric power development is, therefore, distinctly toward the building of larger and still larger units for the production of electricity and the concentration of these large units in power plants of tremendous capacity. Such plants will produce electric power so cheaply and, when several are operated in parallel, so reliably that isolated plants cannot compete, resulting in better and better loading conditions and still better production economies. Central station energy will soon be almost universally used, isolated power plants being justified only when exhaust steam can be used in place of live steam, which would otherwise be required for heating buildings or for other uses. E. M. HERR

The Prospect of Railroad Electrification

The rapid and complete disappearance of the use of animal power on street railways and the phenomenal growth of the electric interurban has led to the popular belief that the supplanting of the steam locomotive is to be a similarly rapid development involving the immediate electrification of our steam railroads. This cannot be the case. The problems are widely divergent. The function of street and interurban railways is that of serving the convenience of their passengers with small units and frequent service. In steam railroads the passenger service is generally the least profitable part of the business and is maintained at its usual high efficiency by the requirements of public convenience and demand. There can be, for instance, no inherent economic justification of Pullmans, limited trains or commodious terminals.

It is the freight traffic which furnishes the most profitable revenue. The problem of the steam railroads, therefore, is to secure in the movement of their freight the utmost that efficiency in methods, equipment and facilities will produce. The United States, as compared with the older countries, is one of vast distances. Hence the great importance of cheap freight movement. The natural resources are prodigious and, while the growth of traffic of the country has been phenomenal, the ability to move traffic economically has not kept pace with the requirements of this tremendous growth. In asking a prominent official, who for forty years was connected with one of the greatest railroads, the ultimate requirement for traffic, his response was, "I don't know. The United States is a great country and this is a great railroad."

The revenue per ton-mile for the heavy tonnage products is amazingly low, and efficiency of operation is a controlling factor in the country's welfare. The increase in capacity of rolling stock has been large; steel cars of great capacity are now in use and those of still greater capacity are considered; locomotives have been increased in capacity to correspond, resulting in a great increase in train weights and the more efficient use of track and terminal facilities.

With the development of the country, the ability to increase track facilities without prohibitive expense is rapidly disappearing. The further cost of maintaining existing facilities on account of the great increase in taxes is also becoming a great burden. The economic problem, therefore, is to obtain from existing facilities the maximum possible service. For the accomplishment of this the answer is the use of electricity.

On an electrified railroad the horse-power which may be made available for train propulsion is almost unlimited, permitting corresponding increases in speed of trains and frequency of movement. The most conspicuous example of this is the Norfolk & Western electrification of the Elkhorn grade. Here steam power of the highest type—Mallet engines, mechanical stokers and superheaters—had reached the limit of traffic movement over these tracks, yet operators on this section state that the use of electric locomotives has doubled their track capacity. The existing electrifications in the United States have been dictated by a variety of reasons, among them tunnel operation, legislative enactment, peculiar local conditions, public opinion for passenger service and, in two cases, congestion of traffic—the Norfolk & Western for freight traffic and the Pennsylvania Railroad at Philadelphia for passenger traffic.

Of several alternative methods, the estimates of cost are practically a stand-off. For comprehensive electrification, the use of overhead conductors is no longer a point of argument, as all are agreed on its necessity. For the generation of power in both hydro-electric and steam plants, the use of alternating current was fixed long ago. For the economic transmission of power alternating current has been standardized for years. All systems are common in these respects. The secondary distribution and conversion may be accomplished by several methods, as may the details of the locomotive equipment.

The question of immediate importance is to secure great concentration of power in a locomotive that shall be efficient from the viewpoint of mechanical construction and its effect upon the railroad way and structures. By necessity the steam locomotive happens to be a very excellent mechanical assembly to secure ease upon the railroad way. The boiler and cylinders, comprising the great mass of the engine, necessarily have to be loosely mounted on springs upon the driving and truck wheels, securing thereby great flexibility and high center of gravity. The American track structure and its maintenance have kept apace with the increase in weight of the locomotive assemblies. The electric locomotive, on the other hand, has no such inherent necessities of assembly, and consequently more service and experience is apparently necessary to determine how near to the drive and truck wheels the motors which furnish the prime rotary motion may be assembled. The standardization of this important question far outweighs any discussion as to details of electrical design or systems on locomotives and secondary distribution. With continued experience, designs should come to more or less of a common standard, as has been reached in street railway motors and electropneumatic control. This will secure economies in construction, so that the disparity in cost per pound between steam and electric locomotives will be lessened.

The unit cost of the overhead contact system will also be greatly diminished with the advent of more simple designs of construction for both main line and yard tracks. The importance of this can scarcely be overestimated, as the unit costs are so enormously multiplied in any large mileage.

It is not anticipated that a further reduction of any material extent in the price of electric power can be realized in these days of increased cost of service and commodities. Under present conditions of high prices, advantage has been taken of the only remaining factor which could effect a reduction, namely, by the production of large units of improved design.

It is assumed that an increase in capacity in the use of railroad facilities is to be the essential in the near or immediate future on many railroad properties. It is apparent with the mounting costs of materials and labor, the increasing burdens of legislation and taxes, that an increase will be required in rates. To limit the amount of this increase the railroads should possess financial ability to secure the highest economy of increased traffic movement, i. e., by means of electrification. It is a problem deserving of the most serious consideration by public opinion to secure to the railroads the sinews in the way of financial return in order to establish the credit needed to obtain capital underwritings. Until public opinion secures this position for the railroads there can be no extensive electrification of railroads and, obviously, no such expansion of manufacturing and engineering facilities as is required for the establishment of those standard methods to secure the highest economies of design and manufacture requisite in such vast undertakings.

The electrical manufacturers are, however, hopeful, as there is a growing belief in the necessity of and favor for a square deal for the railroads—the greatest potential industry of the United States. F. H. Shepard

Cost of Electrical Raw Materials

The past twelve months have witnessed a great expansion in general business, and an unprecedented increase in the values of nearly everything which enters into the construction of electrical apparatus. Raw copper and steel especially, and practically every other material that is employed either directly or indirectly, now command prices that a little more than a year ago would have seemed prohibitive and, even at that, the materials are hard to obtain. The question in everyone's mind is,—will this situation continue, and if so, how long? There is no doubt, however, that to a considerable extent the high price of copper and steel at the present time is due to the large exports which are being made, either in the shape of raw material or in war munitions. Combined with this heavy export demand is the easily confirmed fact that our domestic demand for both copper and steel is approximately twice as great today as it was two years ago. Two peak loads have been superimposed on the producers of these metals, hence the seeming scarcity and high prices.

While the complexion of the war has changed materially within the past few months, according to such reports as have come to us, the change seems to be one which forecasts an increase in the demand for steel, copper and war munitions, rather than a decrease. Moreover, neither side to the controversy seems, at least at the present time, to be gaining any such decisive advantage, either in the field or in finance, as to indicate an early termination of the strife. Best authorities indicate a belief that it will continue for at least a year, and possibly for two years more. It would, therefore, seem a certainty that, at least as long as the war continues and probably for a time after the cessation of hostilities, the demand for copper, steel and other raw materials for export will be maintained at a high level. Our domestic demand, further, continues to be fairly constant.

Another condition which has a very important bearing upon the cost of both raw material and the finished products at the present time is the greatly increased wages for all kinds of labor which now maintains in this country, due largely to the pure question of supply and demand. The simple matter of the relative wages of labor is not the whole story as, on account of the limited supply and perhaps some other causes, the efficiency of the labor *per se* from a productive viewpoint is materially less than it has been heretofore.

Under these conditions, we believe that the prospects for the immediate future are for higher rather than for lower prices on all kinds of material which involve the use of these two metals, which are so vitally important to the electrical industry. C. S. Cook

Developing Inspection and Maintenance Systems

It is recognized that the electrical engineer who lacks a thorough grasp of mechanical engineering is at a great disadvantage in the work-a-day world of this profession. Years ago the writer, while on electrical construction work, found that it was an uphill task to try to make a mechanic out of an electrician-workman. But it was comparatively easy to make an electrician-workman out of a good machinist, as a brief course of instruction results in a real electrical construction worker. In other words, the average electrician lacked the mechanical turn of mind. He had no adequate conception of mechanical laws. It is this class of electricians that contribute most to electrical equipment failures on electric railways.

The efficient controller inspector, first of all, should have a fair machine shop training. If he lacks a mechanical turn of mind he will seldom make a good electrical inspector. The electric railways must have efficient inspection and maintenance systems in order to approach satisfactory operation. Such a system insures reliable performance of the cars, maintenance of schedules, etc. It also reduces costs. Therefore considerable thought should be given to the development of such a system, and especially to the training and development of young men for equipment inspection work.

On the big systems it is comparatively easy to develop men, but on the smaller roads it is more difficult and apparently is being neglected. The reason for this neglect is, without doubt, that the average railway manager on this class of electric railway properties has not had the time to study this detail. The caliber of the control and motor inspectors is left to others, and the others have to be content with the kind of men such jobs attract. This is why so many properties have to look to other roads or elsewhere to get a man if their control inspector quits. Thou-

sands of technically trained boys are being turned out by the engineering schools every year. Where are they going? They line up for the big manufacturing plants and big steam or electric railways; they fight shy of the smaller electric railway properties. In this they make a mistake. They would unquestionably secure better all-around experience on the smaller railways. However, they seem to feel that their prospects are better with the big concerns. They fail to realize that their competition is a hundred times greater in the race for advancement and that the big concerns are of necessity divided up into numerous departments and they must spend months in each, whereas on the smaller railways they would be in touch with all-around experience each day, and if they made good on the smaller property their opportunities with the larger ones would not be lessened.

We all know that technical training, no matter how acquired, either at school or by individual effort, is in greater demand than ever. The electric railways are not getting their quota. The technically trained man will not pay the price in the form of several years at monotonous routine inspection or maintenance work. Railway managers should therefore study this problem. Several roads have apparently solved it by appointing technically trained men, with a few years' practical manufacturing experience behind them, as equipment engineers or assistants to the master mechanic and put the responsibility up to these men to develop and train all classes of inspectors, of course, under the guidance of the master mechanic. This work attracts thinking college men. It is, of course, expected that such jobs will earn a big return on the investment, as the duty of the equipment engineer is to investigate all leaks, such as increasing maintenance costs of this or that detail, such as bearings, brushholders, etc., which must be run down and corrected. If he is not able to do this he is not the right man for the job.

With a fair sprinkling of this type of men coming along on the electric railways, efficiency would naturally increase. The railways would soon begin to advance such men to transportation departments, thence to managers. It is a very great advantage to a transportation superintendent if he has a good working knowledge of his electrical and mechanical equipment. This, of course, applies also to an even greater degree to the manager. Hence it would seem logical to advance men from the mechanical departments to the transportation departments, where they would acquire the important faculty of dealing with and furnishing service to the public.

Many electric railway managers of today grew up in transportation departments and, as a result, give more thought and consideration to the traffic and passenger departments than to the mechanical departments, when, as a matter of fact, the repair and maintenance departments should be the nursing ground for developing men to fill positions in other departments where knowledge of track, equipment, signals, etc., would be a great advantage to them.

MYLES B. LAMBERT

Electrification the Solution for Congested Railway Service

For several years the Broad Street station of the Pennsylvania Railroad at Philadelphia had become more and more inadequate for handling the growing commuter business. The point was finally reached where electrification offered the only solution of the congested passenger service conditions. A searching analysis of the situation by the engineers of the road led to the 11 000 volt, single-phase electrification of the Paoli branch as offering the logical solution for the immediate problem, and at the same time allowing adequate provision for future expansion. Eighty-five trains of from three to eight cars each are now being operated daily, and the service involves over two million car-miles annually.

The success of the electrification of the Paoli branch has led to the extension of the electrified zone; the work being actively pushed on the Chestnut Hill branch.

The electrification of the western end of the New York, New Haven & Hartford Railroad, although undertaken originally for other reasons, is today a further striking illustration of the practical operation of a passenger traffic too congested to be handled by other than electric motive power.

The complete fulfillment of expectations in the electric haulage of their passenger trains, and the available power, led the New York, New Haven & Hartford Railroad to extend the electrification idea to their congested switching yards, at Oak Point and Harlem River. The ability of the electric locomotive to remain for long periods in continuous service, and the great flexibility of this type of motive power in action, furnished prompt relief in these overloaded yards, and the tonnage offering has been handled with dispatch and satisfaction. The freight, as well as the passenger and switching services of this road, has also been much improved by the electric locomotives.

The Norfolk & Western Railway Company has for years been faced with a demand for increased capacity over their Bluefield Mountain Grade Division. Their steam motive power has been kept well abreast of the times, culminating in heavy Mallet locomotives equipped with superheaters and mechanical stokers. Their rolling stock was also second to none in the percentage of revenue tonnage in the train. Nevertheless, the coal development in the field served by the railroad demanded a still more effective outlet. A condition was reached some three years ago where the only practical relief seemed to lie in electrification. Analysis of the problem by the engineers of the road again pointed to a single-phase installation, and electric locomotives were constructed capable of hauling their standard trains at a speed double that accomplished by the Mallets.

The track layout and train movement of this division make it practicable, with careful dispatching, to effectively capitalize the higher and positive speed characteristics of the locomotives supplied, and all steam-haulage records of this "neck of the bottle," and therefore

of the entire railroad, have been far surpassed by the records established with electric haulage. In addition to establishing a new standard for speed of mountain freight drags, this installation is the pioneer demonstration in America of the practical value of regenerative control on the down grade. It is, further, the first installation in the world where polyphase motors have operated commercially under a single-phase trolley wire, and it stands pre-eminently alone in the magnitude of tonnage handled electrically.

The successful installations of electric motive power in congested districts and in all three main branches of railroad service are a positive entering wedge, and the near future will undoubtedly see larger units and heavier service hauled electrically. These further electrifications, however, must be undertaken only where thorough financial analysis gives justification. Fortunately there is enough of this legitimate business to occupy the full attention of the parties interested in the production of electric motive power. G. M. Eaton

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Central Stations and Electric Railways

At the outset of the electric railway and central station development, the two utilities were serving apparently dissimilar fields. Each appeared to have its own problems to work out, and the solution of these various problems was a necessary prelude to the rendering of satisfactory service, the fundamental necessity for any utility to provide if it hoped to grow and expand. It was only natural, therefore, that the electric railway should depend on its own equipment and organization for a source of power supply, since the central station at the outset was simply a lighting, rather than a power company. As a result, the two utilities for many years had power systems entirely independent of the other. When alternating-current distribution became available, the electric railways in most cases selected the lower frequency, 25 cycles, as being more suitable for railway work with apparatus and equipment then available. The central stations, on the other hand, were developed mostly with a frequency of 60 cycles, which was considered most suitable for lighting service.

As the business grew, the power load became from year to year a greater factor in the central station business, until today central stations are primarily power companies and the lighting is to some extent a by-product. With progress in the art, improvements were effected in the apparatus and, through the introduction of the steam turbine into universal use and improvements in conversion equipment, such as rotary converters and motor-generators, there is today available for power supply to electric railways 60 cycle equipment comparable to, and in fact equal to, the well-established 25 cycle apparatus.

The electric railways have for sale a commodity—transportation. They are organized and operated with the one idea—selling transportation. Their problem is to provide transportation for public consumption. The problems of power generation are, therefore, necessarily incidental and not their principal interest. The central station, on the other hand, is first and last in the business of manufacturing and selling electric power. It is a specialist in this field and is organized and equipped to render service in the disposal of its commodity. The combination in some localities of companies having both electric railway, power and lighting interests emphasized and demonstrated the economic advantages of serving all classes of load from a common source.

Having the precedent of a few cases where the railways and power systems were served from a common generating source, it was inevitable that the power companies seeking for increased load, diversity factor and improvement in load factor, should pick on the electric railway as a desirable prospect. There are numerous cases in this country where urban electric railways are purchasing power from central stations, and very many interurban roads are doing likewise. In practically every case the result is advantageous to both parties to the agreement. The electric railway management is relieved of power generation and can devote its entire attention to providing transportation. The central station has secured a valuable customer, with a resultant improvement in its system load factor. Within the last year two interurban roads have adopted central station service, even though the change involved a change of substation equipment to utilize 60 cycle power.

Indications seem to point to a much more extensive getting together in this manner in the near future. A careful study and analysis of many situations will, no doubt, show advantages to both electric railways and central stations in carrying the railway load on the general power system. E. P. Dillon

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5000 Volt Direct-Current Railway

On September 1, 1916, the 5000 volt car equipment on the Grass Lake Division of the Michigan Railways Company, which was described in the Journal for October, 1915, completed 37 000 miles of commercial operation, of which 30 620 miles were made on the 5000 volt line. Considering the radical increase of voltage for this equipment over any previously tried in commercial service, its success has been phenomenal. Aside from a few minor mechanical defects, which had nothing whatever to do with the voltage of the equipment, the troubles may be summed up as follows:—

1—Two cases of grounded main resistance. These both occurred very early in the winter, during a heavy snowfall, when everything under the car became covered with wet snow. The chief cause of the breakdown was asbestos-covered cable used for the resistance leads. The adoption of better insulation completely cured this trouble.

2—Three cases of grounded lower commutating field coils occurred during the spring, due to water entering the motors from running for several days through a pool of water several hundred feet wide and six to nine inches above the top of the rails. These field windings,

being always connected on the ground side of the armatures, were insulated with the usual 600 volt insulation. It was found, however, that with all of the field windings in series and the battery between the windings and ground the voltage on the field coils at starting occasionally reaches 900 or 1000 volts. A better and more water-proof insulation was the remedy for this trouble.

3—One armature defect caused by an open circuit in a lead. This burned a hole in the armature hood, but when the armature was removed for repairs it stood a test of 12 000 volts to ground, so that a new lead was spliced on and the armature returned for service. This occurred after the car had run 30 000 miles.

4—One grounded armature, due to lightning which struck the car last spring a few days after a 44 000 volt transmission line had dropped on the trolley and destroyed the car lightning arrester.

5—One grounded piston insulator in one of the switch groups, due to the same cause as No. *4*.

There have been many reasons why the car could not be kept in service continuously, but they were, for the most part, due neither to the car equipment nor the substation, which has operated successfully throughout the year. However, a very good mileage was obtained during the worst months of the winter season, the car operating for 10 days at one time, 19.5 hours per day, without interruption, and the fact that the car operated about 34 000 miles in a year with only a 15 mile schedule indicates that it missed very few opportunities.

It will be noted that there were no cases of trouble from flashing or from short-circuits. The motors commutate fully as well as high-class, 600 volt, commutating-pole motors and are just as free from flashing. When flashing has occurred, as it has a few times, due to such causes as broken brushholder cables, which were suited to the current-carrying capacity but had not sufficient mechanical strength, the damage has been negligible. Furthermore, in no case have the switches suffered in the least from opening under heavy load conditions. Of course, the violence of a short-circuit is greatly lessened by the limited capacity of the substation and the regulation of the transformers, but the performance of the switches under regular service conditions is such as to give great confidence in their ability to operate under the worst conditions. The indications are from this equipment that it is much easier to handle high-voltage current than an equal amount of energy at low voltage.

The auxiliary equipment has been a complete success, the only work done on the storage battery consisting of the addition of a little distilled water at intervals of about ten days. The battery receives the most of its charge from operating in series with the main motors on the high-voltage part of the line, but the equipment is arranged so as to receive a charge also from the trolley when operating on 600 volts.

One of the greatest annoyances in connection with high-voltage, direct-current installations is flashing in the substations resulting from short-circuits on the line. It is well known that up to date it is impossible absolutely to prevent flashing on commutating apparatus, such as converters or generators, in case of excessive short-circuits. These difficulties have been overcome to such an extent as to make them more an annoyance than anything else, but it may be noted that the successful development of the mercury vapor converter will entirely eliminate the commutator with its flashing troubles from the substation. It will also lessen the violence of short-circuits by introducing the transformer, which acts as a buffer between the power system and a trolley. It is to be hoped that the completion of the development of this valuable apparatus will not be much longer delayed. NORMAN W. STORER

Train Operation in Cities

The first lot of an order of sixty new cars adapted for either independent or train operation have recently been placed in service in Toledo. Up to the present time the Public Service Railway Company of New Jersey is possibly the only urban railroad property in the country where the coupling of surface cars into multiple-unit trains is an everyday operating condition. Considerable credit is due the Toledo Railways & Light Company and the Henry L. Doherty Company for their courage in incurring the necessary extra expense for an equipment which, while having great possibilities for economy, yet has not been tried in this particular field on a very extensive scale.

From the standpoint of public policy, the car and its crew constitute a very important point of contact between the railway company and its patrons. The general public realizes that the actions of the crew, while determined largely by instructions from headquarters, are governed to a considerable extent by individual personality and thus that they secure through conductor and motorman only a dimly reflected impression of the attitude of the utility management toward its patrons. In the case of the car itself, however, the riding public recognizes that, in such important matters as the purchase of rolling stock, the policy of the management may be seen directly in the types of cars provided and in the general schedule of service. As a means, therefore, of securing a satisfied patronage, well-designed, scientifically-constructed cars, which afford easy and prompt entrance and egress, have quick and positive acceleration and deceleration, which are provided with the most approved devices for the comfort and safety of passengers, are certainly a form of investment that warrants consideration from a broader viewpoint than merely that of relative first cost.

The article in this issue by Mr. C. A. Brown outlines the circumstances leading up to the decision to adopt train control in Toledo and describes the cars and their equipment. As the cars are just being delivered it will naturally be some time before the full possibilities of the new type of rolling stock are realized.

A. H. MCINTIRE

A Discussion of Present Conditions in the Electrical Industry*

E. W. Rice, Jr.
President,
General Electric Company

THE electrical manufacturing business during the early part of 1913, in common with other business in this country, enjoyed prosperity. A decline, however, set in during the autumn and winter months of 1913-14 which was accelerated by the outbreak of the great European war in August, 1914. Our business did not show marked signs of revival until orders placed in this country for the belligerents had reached a considerable volume. Improvement due to this latter cause was noticeable in the summer of 1915, and by autumn of that year orders, particularly for large apparatus, were being received in unprecedented volume; and while the volume of business during recent months has shown some recession, orders are still being placed at a rate in excess of anything in our previous experience. As far as we have been able to observe, this condition applies not only to our business, but to practically all other business, particularly in the field of machinery and metal products.

The situation which I have described has brought about general manufacturing conditions which are, from a production standpoint, extremely unsatisfactory. Stocks in the hands of manufacturers and dealers in metals and machinery, which were allowed to become depleted owing to the abnormal reduction in business, were quickly exhausted upon its revival. All manufacturers and dealers in such materials and appliances soon became overwhelmed with orders, and consequently there has been for the past year, and still continues to be, the greatest difficulty in obtaining raw materials and equipment, particularly those of a special nature. The demand for copper and brass materials, iron and steel, sheet steel, castings, forgings, etc., has for some time greatly exceeded the capacity of the producing concerns in this country. Promises made by producers of raw materials and machinery and tools, of every description, have been found by sad experience to be extremely unreliable, and this naturally interferes with our schedules of manufacture of finished goods. There is little, if any, evidence of a change in the situation in the immediate future, and we anticipate that tremendous difficulties will continue to be experienced in obtaining raw materials.

As a result of oversold conditions, prices have been advanced to unprecedented figures. For example, copper, which was selling in August, 1914, at about 12.5 cents per pound, rapidly advanced to 28 and 30 cents, and is now holding at about 23 to 25 cents, according to delivery required. Sheet steel for electrical purposes has advanced from 45 to 85 percent; iron castings, from 15 to 25 percent; steel castings, from 20 to 25 percent. Ordinary zinc advanced from five cents per pound to 25 cents, or over 500 percent, but a few months ago it began to react and is now selling at about eight cents per pound, some 60 percent above normal; and aluminum has advanced, according to condition of contracts, from 100 to 250 percent.

The above materials are the foundation of our business. Other important materials which enter into our manufacture, such as tungsten, mercury, ferro-manganese, asbestos and paper have also greatly advanced. Tungsten, for example, climbed for a time to over 900 percent, and is now over 250 percent above normal; mercury advanced over 700 percent and is now double the normal price; ferro-manganese advanced over 700 percent; asbestos over 150 percent, and paper from 50 to 100 percent.

This remarkable situation is well illustrated by the machine tool market; prices were constantly raised and deliveries lengthened until, some six months ago, the most reputable manufacturers, manufacturing the highest grade of standard tools, began to quote merely nominal current prices subject to an advance in price not to exceed 20 percent at the time of shipment. I quote a clause which now appears to be the standard with many machine tool builders:—

> "The price of machines for 1917 delivery to be that prevailing at the time of shipment with a guarantee that the advance, if any, will not exceed approximately 20 percent of the current price quoted above, as per our letter of even date."

This is taken from an actual quotation to our company on August 4, 1916. They also informed us that the above prices, named for prompt acceptance only, are subject to change without notice.

The increase in prices of raw materials and machinery has not been permitted to directly affect production unfavorably, as these prices have been met. The fundamental difficulty which has constantly interfered with production schedules has been the inability to get machinery and materials either on time or in sufficient quantities to keep our factories operating in an efficient manner. In some instances materials and machinery

*An address delivered at the annual convention of the Association of Edison Illuminating Company, at Hot Springs, Va., September 4-7. Reprinted by permission.

which heretofore have been employed have been unobtainable and new materials, machinery and methods have been substituted, all of which has involved delay in production. Even after we had succeeded in purchasing our raw materials, and shipment had actually taken place at the point of manufacture, there was no assurance that the materials would arrive on time. The railroads, as is well known, became so congested that deliveries were slow and uncertain, and complete embargoes were frequently placed upon the delivery of important materials, and always, it would seem, at the most unfortunate time for ourselves and our customers.

The manufacturer, however, needs something more than buildings, machinery and raw materials in order to fill the orders of his customers. He must have labor of good quality and of reasonable and reliable supply, and manifestly it is impossible to cope with the increased volume of business without an increase in the efficiency of labor or an increase in quantity.

It is natural and proper that laborers, both skilled and unskilled, should seek to share in the general prosperity, and we, in common with other manufacturers, endeavored to meet the situation promptly and liberally. In spite, however, of all our efforts the labor situation for the last year has been, and still remains, in a very unsatisfactory condition, especially with reference to high-grade skilled employees and low-grade common laborers. There does not seem to be a sufficiency of either class to meet the demands of production in this country. As is well known, the scale of wages of such employees is abnormally high, which condition has been intensified by competition among the manufacturers themselves. Many manufacturers of war materials have been particularly energetic, even offensive, in their competition for labor and have done much to demoralize the labor situation. Of course, these manufacturers realize that their work is largely of a temporary nature and will not, in most cases, extend beyond the cessation of hostilities in Europe, and naturally they wish to "make hay while the sun shines." To meet the demands, large new shops have been erected, which had to be manned, and in doing this the most ruthless competition has been inaugurated, and is still in effect.

It is also well known that the great decrease in emigration, due to the European war, has created a serious shortage in ordinary labor, and there is a real scarcity of such labor in all parts of the eastern and middle states. Such labor now commands the highest wages ever paid it, and there seems to be no immediate prospect of increase in the supply.

The increase in the price of labor would not in itself affect production adversely; it might, in fact, under proper conditions lead to a stimulation and improvement of production. However, unfortunately there is every evidence that the efficiency has, temporarily at least, declined and the output per man is lower than it has been heretofore, at a time when it is to the interest of all men engaged in the industry, as well as the employers, to obtain the highest possible output. Unfortunately also for efficient production, it has been apparently impossible to make the needed adjustments without frequent strikes, which in several instances have been of long duration and naturally have interfered seriously with the efficiency and output. Unfortunately, we have not been free from this calamity, having experienced during October and November of last year a strike of six weeks duration at our principal works, in which from 12 000 to 15 000 employees stopped work for the period stated. Deliveries of materials and machinery upon which we were relying have also been interrupted at critical periods by strikes among those from whom we purchase such articles.

EFFECT OF MUNITION CONTRACTS ON THE PRESENT SITUATION

I have been especially asked to say something about the effect of munition contracts on the present situation. The large contracts which have been taken for war munitions have unquestionably affected the general manufacturing situation. They have created a demand for enormous quantities of brass, copper and steel and are largely responsible for the condition in which the producers of such materials find themselves, viz., almost complete inability to fill orders. Munition orders also, without doubt, have had a profound influence upon prices of raw materials required for their manufacture, and the higher level of prices of all materials is, to a considerable extent, due to the demand which orders for war munitions have created. This condition is not confined to materials, but also extends to machine tools. Manufacturers of munitions, both abroad and at home, have ordered machinery, such as lathes, automatic screw machines, drill presses, and other standard lines of tools, in enormous quantities and have overwhelmed the manufacturers. The demand for such machines and tools for the manufacture of munitions has been so great, for a time, as to absorb the entire output of the country, and consequently it has been, and is still, very difficult to obtain tools required for the manufacture of regular lines of product, and this has naturally in turn interfered with our schedules for increased production.

As has already been stated, the creation of large munition plants, and the undertaking of the manufacture of munitions, has created an abnormal demand for labor, and has, in spite of the increase in wages, resulted in an absolute shortage of labor of all kinds.

I suppose, however, that you are particularly interested to learn as to what extent, if any, the manufacture of such material by our company has interfered, or may interfere, with deliveries of our regular product. I frankly admit at once that such contracts as we have taken for munition work have, and will until completed, interfere to a relatively limited extent with our regular business. I may further confess that if we had anticipated the prompt revival of business, to say nothing of the phenomenal increase in our regular business, we would never have undertaken the manufacture of any munitions.

Having made the above statement, however, in the interest of frankness, it is only fair to explain that at the time when these contracts were undertaken many of our departments had been running for some time at from 25 to 60 percent of their normal capacity. We therefore had an abundance of idle space and tools, and although we had placed in stock, in anticipation of orders, a large amount of material, we felt that we had reached the limit of prudence, and were at the point where we faced a continued decline in our production and the further loss of tried, valuable and skilled employees.

Our entrance into the munition field was therefore undertaken largely with a view of filling some of our vacant space and furnishing work for our employees. Moreover, long before the vacant space that was available for such work was occupied we erected additional buildings and also purchased additional idle factories for the express purpose of providing room for munition work without, as we then thought, any interference whatsoever with our standard work.

I would also state that none of the space which we normally devote to the manufacture of turbines, induction motors or other similar apparatus has been occupied at any time for the manufacture of munitions, and that the total space occupied in munition work of all character is today but three percent of our total manufacturing space, much less than the proportion in value of our munition orders to orders for our regular product. Moreover, our last important order for munitions was taken over a year ago, and we do not now expect to take any further orders of this nature. The reason why the space occupied and the men employed on munition work is relatively less in proportion to its output in money value than our standard product is that munition work is fundamentally a better manufacturing proposition; it consists of many thousands of articles which are absolutely identical not only in design but in size, which naturally permits of a greater output per man and per square foot than a product that is variable and special, as is our electrical business.

POSTPONEMENT OF SHIPPING DATES ON 1916 CONTRACTS AND PROBABLE DELIVERIES ON 1917 CONTRACTS

I think it can be safely said that most large manufacturers have found it necessary to extend shipment dates on a portion of their 1916 contracts. The difficulties of obtaining raw materials, labor of proper quality and mechanical equipment have, as heretofore stated, interrupted and slowed up manufacturing and created conditions which cannot but result in deferred shipments, on a portion at least, of the output. This is a cause of great anxiety to us as well as to our customers. We are sparing no expense in procuring materials or devising ways and means, as far as may be practicable, to maintain our schedules. In some instances our customers, due to the fact that they have been disappointed in deliveries by contractors for other materials which are needed, have found it possible to permit postponement of our deliveries without adding to their troubles, and have kindly permitted us to postpone such deliveries, which in turn has enabled us to help other customers who were in a different situation.

At this time it is difficult to express a definite opinion as to deliveries on 1917 contracts. We have taken large contracts for delivery in 1917, and in some cases even for 1918. We are contracting for important materials as far in advance as seems to be necessary in order to insure deliveries. In order to be assured of a supply it seems to be necessary to place orders for some materials well into 1917. In such cases we have not hesitated to take the risk.

INCREASED PRICES FOR 1916 AND RELATIVE PRICES FOR 1917

I have also been asked to say something as to increased prices for 1916 and relative prices for 1917. The great increase in the cost of raw materials and labor, as well as other items of expense, have made it necessary for us to increase our prices. We have not, however, advanced our prices more than necessary to cover increased cost of manufacture. In some classes of apparatus, through the skill of our engineers in redesigning, without sacrifice of quality, we have effected economies offsetting, in part at least, the normal increased cost, and in such instances our prices have not been increased to the extent that otherwise would have been necessary.

As to future prices, we are so completely dependent upon the prices which we must pay for raw materials and labor that it is impossible for us to express an opinion which would be of special value. It would almost seem that the high-water mark with respect to prices of raw materials and labor has been reached and, if so, with a continuance of such conditions, future prices of raw materials would naturally remain substantially unchanged. Of course, upon any extended reaction in business, which some authorities assure us will take place upon the cessation of hostilities, prices would naturally decline. However, I am not a prophet and am glad to leave to others better fitted than myself to entertain us with their views as to what the future may bring forth.

I may say, in this connection, that in spite of the uncertainty as to the business outlook after the European war is over, and in disregard of the abnormally high cost and difficulty of construction work, we have started a large amount of building operations which will give us a greatly increased output in the future, provided, of course, that we can secure the necessary materials and men. We should, therefore, be in even better position in 1917 to fill our contracts on time.

It has been suggested that the large profits on munition contracts have established a precedent which may have a bearing upon the electrical business. I do not share in this view, as the electrical business is highly competitive, and in normal times the volume of demand is less than the combined facilities of all the manufac-

turers. On the other hand, the demand for munitions has far exceeded the existing facilities of every description and prices have been high in consequence.

I am glad to state that in spite of all the difficulties with materials, labor, transportation, etc., which have made it impossible for us to realize the full output of existing facilities, nevertheless, our manufacturing organization has succeeded in not only maintaining but in greatly increasing our output as compared with previous years, although, as already stated, this increased production has unfortunately only been obtained at a great increase in cost, which let us hope is temporary in character.

In conclusion I wish to express my hearty appreciation of the opportunity to talk to you this evening. I have been enjoying the meetings of the Edison Association for about a quarter of a century. It is my mature judgment that it would scarcely be possible to exaggerate the importance and value of the contributions of this Association to the success of the electrical industry of which we form a part and are all vitally interested.

At your meetings have been gathered the pioneers of the industry. Revolutionary discoveries and inventions have here received their first introduction to the public. Constructive criticism, free and frank discussion, sincere and effective co-operation between manufacturer and members has resulted in such practical progress as to be the wonder of the world. Meetings have been eagerly looked forward to from year to year and have proved the greatest stimulus to increased effort. It has been a privilege and a joy to thus work together for so many years. The result stands as an unbroken record of continuous expansion of the industry in volume and in the variety and number of its useful applications to the service of the public, a constant reduction in the cost of the manufactured product, all accompanied by a most remarkable improvement in the quality and in the character of the service rendered to each other and to the public. By manufactured product I mean, of course, to include not only the product of the manufacturer of electrical machinery and devices, but also that of the central station which supplies electrical energy and light to the public.

We hear much said nowadays about setting business free, and men may differ as to the truth of the claim or even as to the exact meaning of the expression. But there can be no question as to what the men of the electrical industry have done. They have created a business valued at hundreds of millions, even billions of dollars, given employment to hundreds of thousands of men and women, and conferred untold benefits, comforts and luxuries upon millions of human beings. If the past is a promise of the future, then indeed the electrical industry has a most brilliant and useful future. I believe that it has, yet I must admit at times to a feeling of uncertainty akin to despondency. For this wonderful business which you have created has expanded until it touches the lives of millions of the people; men who know nothing of its origin or nature have risen and are attempting by political methods to control and regulate it. I sometimes tremble lest the "valor of ignorance" should prevail over the wisdom of experience and our progress be thus stopped. This indeed would prove a public calamity. The remedy is, as has been many times suggested, the proper education of the public, and through it of our political rulers as to the character and value of our work.

I am happy to note that you are aroused to the dangers that beset you, and I have confidence that those who have created and guided this wonderful industry will not fail to co-operate and take all such steps as may be necessary for protection from the attacks of the ignorant and indolent and all other similar enemies.

An Analysis of the Electrical Manufacturing Situation*

GUY E. TRIPP
Chairman of the Board,
Westinghouse Electric & Mfg. Company

IN ORDER to get a comprehensive view of present manufacturing conditions in the electrical industry it is necessary to review for a moment a little of its past history. That is to say, there have been important steps in the development of the uses of electricity which should be kept in mind in order to fully understand the sudden and immense demands that have recently been placed upon manufacturing facilities. I do not intend to weary you by an academic discussion of the relations of electrical manufacturers and public utilities, and I think we may take it for granted that the elementary relationships of buyer and seller are sufficiently satisfactory; but there has been a connection of a different kind between the manufacturer and the central station which has been constantly changing and to which I would like briefly to call your attention.

When the electrical industry began it was something more than the mere selling of a manufactured product. It was the application of scientific knowledge to prac-

*An address delivered at the annual convention of the Association of Edison Illuminating Companies, at Hot Springs, Va., September 4-7. Reprinted by permission.

tical uses and required close co-operation between the manufacturer and the pioneers in the public utility field. The tremendous importance of individual genius was the predominating feature of this period, and manufacturing was largely confined to the development of the particular apparatus which some far-seeing man had invented or developed. As a natural consequence, the same man became an indispensable factor in the application of his conceptions to the public use; and from this condition arose, not electrical manufacturers as they are now constituted, but organizations standing sponsor for and producing goods according to systems developed by the great chiefs of the electrical science. Through these agencies there sprang up a great number of small installations of street railways and electric light companies serving the routine local wants of the ordinary citizen in his daily life. This was the first step in the evolution of the industry.

Perhaps the next stage may be described as that in which the various systems were sifted out, not, however, by the predominance of one or the other but, as is usual in such circumstances, by a combination of the best points of all of them, until the manufacture of electrical apparatus and the application of it became more or less standardized. That is to say, while invention and research went on, and is still going on, and important improvements were made from time to time, and are being made, it is a fact that the large manufacturer of electrical apparatus can and does produce machinery and apparatus that is adapted to any kind of electrical service. When the manufacture of electrical apparatus had reached this stage it made possible the new era of central station development, which resulted in a great expansion of the uses of electricity, the history of which has been a matter of comparatively few years. The isolated electric light plant which had no power business, and gave a local individual service which had no great fluctuations, has passed away and has been replaced by huge central station organizations, which sell a great percentage of their output for uses in all lines of industrial activity and whose business will more and more tend to rise or fall with the general tide of industry. A few statistics which illustrate this remarkable development will be interesting.

The report of the Secretary of Agriculture, with which you are doubtless all familiar, states that 85 corporations control 68.6 percent of the total public service power in the United States. Of these, 35 control one-half of this total, 16 control one-third, and 10 control one-fourth. This does not have reference to the ingenious classification made in the same report of control due to interrelationships through common directors, and for the purposes of this paper that character of control is not important, except for your amusement I might quote what it says about the Westinghouse Electric & Mfg. Company, which is as follows:—

"Plate 18 shows the relations through common directors and principal officers of the Westinghouse Electric & Mfg. Company and the Electric Properties Corporation with each other and with 38 other companies. The aggregate public-service power controlled by the individual concerns appearing within this group is 405 705 water horse-power and 1 989 432 steam-power, a total of 2 395 137 horse-power, or 8.8 percent, 21.3 percent, and 17.2 percent, respectively, of the totals for the United States within each class used in public service operations."

This makes us the third most powerful interest in the United States in control of public utilities; in fact, my friend, Mr. Rice, beats us by only a small amount, we being allotted 17.2 percent of the total operations in the United States and he is allotted 21.3 percent. This may be a good illustration of the more or less (with considerable stress on the less) valuable conclusions that are reached by Government statisticians when they give their imagination full sway. But to come back to the enormous concentration in the electrical industry which has taken place in the last few years and which, whether the Government's figures are correct or not, is an undoubted fact, we can get an interesting picture which explains why the sudden increase in industrial activity immediately reflected itself in a demand for electrical apparatus. The demand was of a kind much more difficult to handle than in the early days because of the large units now required. The market in prime movers has been turned from small units at a relatively high price per kilowatt into a demand for very large units at a relatively low price per kilowatt. The general effect of this is to decrease relatively the value of our factory output stated in dollars; that is to say, an output of a million dollars under existing conditions requires greater factory capacity than an output of a million dollars under conditions existing only a few years ago. This difference has been further emphasized by the further reduction in price of metering and current-consuming devices. On the other hand, the demand for these devices has been greatly increased, due to the more intelligent and energetic conduct of the electrical business under concentrated control, for it is an undoubted fact that scientific management keeps pace with concentration. If this larger demand had not ensued, it would have been impossible to reduce prices of prime movers to their present figure.

I believe that the tendency for combination and consolidation of public utilities is bound to go on from a purely economic standpoint, and that this irresistible tendency will present many political problems for solution, but I have referred to them solely for the purpose of enabling you to better understand that the demands upon the manufacturer, brought about by the sudden and tremendous impetus given to almost every branch of industry in the United States on account of the European war, was the combined result of these great aggregations and the large use made of them by industrial enterprises. That is to say, manufacturing industries of all kinds, which have been recently taught to use electricity as a power, called for an increase in service, the magnitude of which was as unforeseen as it was abrupt.

The following quotation from the annual report of the Chamber of Commerce of New York for 1915 is interesting in its bearing on the unprecedented demand which came upon the manufacturing industries of this country in the last half of that year:—

"All steel products were dragging when the year opened. The belief entertained at the beginning of the war that Europe would promptly call on the United States for large amounts of steel proved to be a mistake, and at the close of 1914 the more common steel products could be had about as cheaply as at any time in the recent years of depression. In January of 1915 there was a slight turn for the better, and steel manufacturers in the next three or four months stimulated buying by announcing that higher prices would be asked month by month. On bars, shapes and plates increases of $1 a month were thus made, and gradually it began to appear that steel requirements of the Allies would really cut a considerable figure in the industry here. As the summer approached the advances became more pronounced, and in the second half of the year prices went up by leaps and bounds. Orders for large round bars for shrapnel glutted the merchant mills having facilities for their production, and a strange development was the diversion of rail mills, which had few orders from the railroads, to the production of large rounds, for which two to three cents or more a pound were received. Premiums were paid for early delivery of products like bars, structural shapes and plates. Plate mills had a veritable harvest, orders for vessels crowded Atlantic coast shipyards, and plates for early delivery were bringing as high as 3.5 cents at the close of the year. The difficulties of the mills in making deliveries constantly increased. Steel billets were in great demand for war purposes, as many concerns forged them into shell blanks. The allied governments were large buyers of such semi-finished steel.

"Pig iron at no time in the year had any approach to the advance made in steel prices. The output in January was at the rate of about 19 000 000 tons a year. At the end of the year it had risen to a rate of 38 800 000 tons a year. For a considerable part of the year pig iron prices were not strong. Makers were timid up to July. An advance of 25 cents a ton on any grade of pig iron was an event, and it was not until August that rises of 75 cents to $1 a ton began to be recorded. In Southern iron the net advance for the year was $5.50. Northern basic iron had exactly the same advance, while Bessemer iron at Pittsburgh went from $14.70 at the opening of the year to $21.95.

"In the early months of 1916 prices went up in an unheard-of way. At the end of April, as this is written, steel bars for early delivery are selling at 3 cents, Pittsburgh, plates at 3.75 cents, and structural steel at 2.60 cents. In a number of cases plates have sold at 4 cents in considerable quantities, and small lots have brought as high as 5 cents. Wire products have advanced since January 1, until fence wire stands at 2.45 cents and wire nails at 2.50 cents, Pittsburgh. Galvanized sheets have gone to 5 cents, black sheets to 2.85 cents, and 3 cents, Pittsburgh, for No. 28, and tinplate to $5 and $5.50 a base box. Rerolling billets have sold at $50, Pittsburgh, and forging billets at $60. Some manufacturers were fearful of the effect of these advances in restricting consumption, but there is little evidence of this apart from the building trade. The steel is in such demand that any falling off in one or two products is only welcomed."

Our own experience will further serve to illustrate how sudden and unexpected this demand was. The war began August 1, 1914. At that time we had unfilled orders on our books of about $8 000 000. This was a small amount and represents about two months theoretical full output of our shops. We had had a strike during the year and business was decreasing; in fact, the outlook was anything but encouraging. Business continued to dwindle, and on February 28, 1915, which was the lowest point we reached, we had on our books approximately $5 600 000 of unfilled orders. In other words, during the first seven months of the war our business had fallen off 30 percent. Our shops were running at not over 50 percent capacity and the total number of men on our payroll was about 14 800.

While February, 1915 was the low period, there was no great improvement for several months afterward; in fact, the real upward movement did not begin until November 1, 1915, at which date we had on our books $8 900 000 of unfilled orders. In order that you may have these figures more clearly in mind, let me recapitulate:—

On August 1, 1914, at the beginning of the war, we had on hand $8 000 000 orders.

On February 28, 1915, which was our low period, we had on hand $5 600 000.

On October 31, 1915, or 14 months after the beginning of the war, which marked the real beginning of the avalanche, we had on hand $8 900 000.

From that time on there was no cessation of increases. Notwithstanding we increased our forces from the figure of 14 800 to nearly 30 000 and ran our factories to the fullest possible capacity, we have on hand today unfilled orders for electrical goods amounting to considerably over $30 000 000. In all these figures I have given I have taken no account whatever of orders for war munitions. I am referring to our regular product, in which, as you have seen, notwithstanding the very large output of our shops during the last eight months, our unfilled orders have increased over the low point of February, 1915, by almost 600 percent.

Now as to the war orders, as I have stated, the latter part of 1914 business presented a dubious outlook, and in June, 1915, we entered into a contract with the English Government to make rifles for Russia. It was a large undertaking and required extensive works. We located the entire plant at Springfield, Mass. First, because it seemed wise to purchase a going concern; that is to say, a manufacturing company already organized and engaged for many years in the particular work in which we were about to undertake. Second, it seemed to be a favorable labor market and so far removed from Pittsburgh as to not interfere with the operating conditions there.

Contemporaneously with that, and at various times before and after, we took contracts for machining high-explosive shells. The principal portion of this work was done in a new building in Turtle Creek which had never been used by us for electrical manufacturing purposes, and a plant in Pittsburgh formerly belonging to the company and which had been leased for a number of years and in which we had no activities whatever. A space amounting to a portion of one aisle in our main shops was devoted to this work for a time, but was removed from it, and now there is no work of that character being done anywhere in the shops. On the whole, the engaging by the Westinghouse Electric & Mfg. Com-

pany itself in munition work has had very little effect on our regular output; that is to say, upon time and amount of deliveries. It has possibly had some deterrent effect on new development, which might otherwise have been carried out, but this is problematical.

I go this much into detail because I wish to point out that, notwithstanding the business conditions which confronted us in 1914 and the first half of 1915, which I have just pointed out, we kept our facilities practically free for our regular manufacturing business. I have now reached the point where I can say something about present general manufacturing conditions.

During the winter of 1914-15, when the electrical business was at low ebb, we were experiencing difficulty in finding employment for many of our regular men. Part time and alternate layoffs were resorted to. It was about this time, as I have said, that the opportunity presented itself to take on some machining of shells. This gave us an opportunity to give full-time employment to many men who had been either working part time or laid off, and a considerable number of our regular men were put to work in the new plant.

As the electrical business increased practically all the old men were transferred to their usual occupations, because it was easier to fill the ranks of the munition workers than our own ranks. Men came off the farms and from other walks in life who had never seen a machine before and within a week were able to operate a lathe doing one specific piece of work, but the problem of increasing the ranks of skilled workmen in our shops in view of the keen competition for labor was a more difficult one; in fact, the industrial balance of the whole Pittsburgh district had been disturbed. War munition plants having sprung up all over the country, creating a demand for labor, offered such high prices that it was difficult, not only to retain a full force of skilled workmen, but it had a serious effect upon the unskilled class who, as I have said, could within a short time be taught to operate a lathe and do one operation and who were able to earn very large wages.

I haven't any figures at hand giving statistics as to the demand for labor upon this special industry, but I should hazard a guess that 150 000 or 200 000 new jobs would not be excessive; and, as the number of men we have employed on munition work amounts to about 4500 in Pittsburgh, it is fair to say that our labor conditions would have been just as serious had we never taken a war order. Our greatest task is to find a sufficient supply of the two extremes, viz., the highly skilled and the common laborer. The first is practically unobtainable and the latter is becoming scarcer, more expensive and less efficient. It is not difficult to hire enough men, but they will not stay. The foreign laborer, as well as the colored man, is essentially a rover, and the rumors of big wages in munition plants throughout the country accentuates this tendency in the laborer as well as in the case of the skilled and semi-skilled.

Most applicants for work of any grade now are "shopping" around for the biggest pay with the least work. The fact that we are engaged in munition work has in itself not interfered with the labor on regular work, for had not we been so engaged the interference of others so employed would, doubtless, have been equally as great. On the other hand, the fact that we had munition work attracted a great deal of labor, part of which was put on other work.

The strike of last spring set us back four weeks or more insofar as deliveries are concerned, but the really great source of delay and curtailment of output has for some time been raw material. It is in this respect that the "munition work" in the country at large has had and is having a marked effect indirectly on our deliveries.

Owing to the nature of our product, coupled with the modern tendency of public utilities to ask for special apparatus, we find it impossible to foretell to a great degree of certainty our requirements for raw and semi-finished material and, although we began a year ago to order large quantities upon estimates of requirements, much material then ordered is not yet delivered. The principal raw materials that we purchase for electrical apparatus are iron, steel, copper and insulating materials. Some idea of our difficulties in securing these stocks may be had from the following:—

In July, 1915, our promises of delivery on steel were for 20 to 60 days after placing of orders. In September and October these dates were lengthened, and in November promises were three months minimum and four months maximum. At that time we placed orders based on business in hand or prospect; on January 26, 1916, we received notice that deliveries would be six months, and on February 18, 1916, another notification was received extending delivery to ten months. It has only been by constant pressure that we have been able to get material ordered as long ago as October and November, 1915; some of it was received in July this year and some has not yet been shipped. It has been necessary for our purchasing department to put a force of men in the field who live at the mills and endeavor to have our material put through. We have also had a corps of men scouring the country picking up steel wherever they could find it.

The copper situation has been very similar to the steel. On January 10, 1916, we received from one of the largest copper manufacturers in the country a statement as follows:—

> "Any orders received by us are accepted only on the basis that they are not subject to cancellation and, in addition, they will be filled as soon as conditions will permit; and, furthermore, that these orders will have to be on our books 30 days before we will even give you any information as to when you can expect the material."

Such a condition of affairs makes the storekeeper's job one of some magnitude.

Rubber-covered wire and cable are among some of the other articles the procuring of which have taxed the ingenuity of everybody from the president down. A general idea of the "material" handicap on deliveries is shown on the following list of some of the more im-

portant raw materials and the time required to get them:—

Aluminum, sheet	
Aluminum, meter discs	6 months
Aluminum, meter covers	
Asbestos cloth	16 to 20 weeks
Brass rod	
Brass tubing	5 to 6 months
Brass sheet	
Copper rods	
Copper sheets	5 to 6 months
Copper tubing	
Copper wire, bare	5 to 6 months
Cotton-covered magnet	5 months
Silk-covered magnet	5 months
Rubber-covered wire and cords	5 months
Drills, high speed	Indef.—5 to 6 months
Drills, standard carbon	4 to 5 months
Drills, special	4 to 6 months
Emery wheels	5 to 7 months
German silver sheet	
German silver wire, bare	5 to 6 months
German silver wire, ins.	
Lamp cord	5 months
Linen, 0.012 inch	60 to 90 days
Porcelain, on wet process high-tension pieces	8 to 12 weeks
Porcelain, on dry process high-tension pieces	8 to 12 weeks
Porcelain, some large and difficult pieces	8 to 12 weeks
Steel drop forgings	120 days
Steel shafts, spec. No. 1476	4 to 16 weeks
Steel shafts, spec. No. 1478	4 to 16 weeks
Steel, bare	10 months
Steel plates	10 months
Steel sheet—Bess. & O. H.	120 days
Steel, cold-rolled strip	6 months
Steel, tool	4 to 6 months
Steel castings	8 weeks
Tapes, asbestos	60 to 90 days
Tapes, bias friction	30 days
Tapes, grey webbing	120 days
Tapes, linen, 0.007 inch	120 days
Tapes, surgical, 0.020 inch	120 days
Tapes, taffeta	120 days
Tools, small	12 to 20 weeks

Up to this point I have endeavored to outline some of the conditions under which we are now working, but I should like to add something from the financial and profit side and to say at the outset that, under normal conditions now and in the future so far as I can foresee, an electrical manufacturer will not be able to earn any more than a fair return upon the actual cash invested in the business; that is to say, no cash returns are to be expected upon patent rights, good will and other intangibles of that nature. It may be possible for a concern to do it for a few years, but it will be because an insufficient amount is being expended in research and development work, and that policy carried on long enough will eventually put any electrical manufacturer out of business.

We expended last year in research and development over $1 000 000, and that amount, of course, comes bodily out of net earnings, because it is an expenditure that cannot bear immediate fruit, and it would only be warranted on the expectation that the general law of averages over a period of years would in a thousand ways add that and more to the money value of the company's business. The amount of money expended directly upon research and development is only part of the story, because it is almost an invariable rule that new or improved appliances are not profitable for a long period of time; that is to say, they are not brought to a satisfactory commercial stage immediately, and many months and perhaps years of losses must be taken before a profitable stage has been reached. In addition, of course, to the unprofitable items which I have just mentioned, there are those which have reached the stage of commercial development, but in which competition is so severe that there are little or no profits.

I do not know how many different kinds of things we make, but I have in mind one classification of our business which consists of about 75 items, either complete in themselves or representing groups and, without regard to the dollar value of each of the items, it is a fact that over 25 percent of them is sold at no profit or sold at a loss. This classification covers our entire output, that is to say, it is not a selected one.

I would not have you understand that 25 percent of the product of our factories is sold at a loss or at no profit, because many of the items to which I have referred represent only a small amount in dollars and cents during the year. On the other hand, some of them represent very large amounts; but from the standpoint of the electrical industry, each one of them is an important part of its development and we cannot abandon the manufacture of them, although if we did its theoretical effect would be to largely increase our profits. As a matter of fact, however, it would probably decrease them. The profits in the business are undoubtedly close. I think our shops are operated with reasonable efficiency and I think our sales department gets as high a price for the product as possible, but until last year, which included war profits, there has never been a year in the last ten years that the Westinghouse Electric & Mfg. Company made (exclusive of interest received on its investments) as high as 15 percent on the selling price of its output. This is a close operation and requires that, for safety, an electrical manufacturing company should turn over its capital, which is devoted to manufacturing purposes, at least once a year.

I feel that it is not necessary to apologize for the frequent reference to my own company, for in no other way could I deal satisfactorily with the subject which you have assigned me, and I feel it is not improper to take this opportunity of expressing to your Association the very deep appreciation of the large and growing business with which you have favored us. I do not mean to indulge in flattery when I state that, in my opinion, the affairs of the great central stations throughout the country are conducted with greater intelligence, with more prophetic regard to the public relations, than most other public utilities, and it is a source of great content to my company that the business upon which it depends to such a large extent rests in such capable hands.

One-Man, Light-Weight Electric Railway Cars

W. E. Moore
Of W. E. Moore & Co., Consulting Engineers,
Pittsburgh, Pa.

It has been truly said that, next to the invention of the alphabet and the printing press, mechanical means of rapid transit has been the greatest aid in promoting the advancement of civilization. As civilization makes its advances along industrial and educational lines, the population tends to group itself more and more around centers, forming villages, towns and cities. As these centers grow in area and population, the necessity for means of rapid transit increases both as to the requirements for intra and intercity traveling. Modern paved streets and roadways have made the rubber-tired automobile a real factor in transportation. The amount of power required for moving loads on steel or chilled iron wheels over iron rails is but a fraction of that required to move the same load over the best of pavements. The cost of pavement maintenance is greatly in excess of the cost of rail maintenance per ton-mile, to say nothing of the elimination of dust and dirt which result from vehicular pavement wear. For these reasons and owing to the excessive cost of rubber tires and the advance in the price of fuel, it does not seem likely that the automobile can ever handle to the best advantage the more important transportation problems in and between cities. Electric power delivered through a contact shoe or trolley wire is by far the cheapest power for transportation so far devised, and is likely to remain so.

W. E. Moore

The public is served best, not only by fast cars, but also by vehicles running on frequent headway and making a minimum number of stops. These requirements make cars of comparatively small capacity desirable from the standpoint of convenience to the public, for with cars seating a large number of passengers the stops become so frequent as to materially retard the schedule speed. The automobile jitney has shown the street railway man the importance of frequent headway for building up traffic, and has made evident the great need for more frequent headway that can only be secured economically by means of small-seating-capacity, light-weight, low-cost, one-man cars. Previous to the advent of the jitney, the tendency had been toward the construction of larger and heavier cars, the railways vying with each other to secure greater size and weight of equipment. This heavy rolling stock, together with the advance in the cost of materials and labor and the decrease in passenger traffic due to increased use of automobiles, has caused more than one electric railroad, which started out with bright prospects, to wind up in receivership, and is largely responsible for the disfavor with which street railway projects are looked upon by investors today.

Within the last three years the advent of the light-weight, one-man car has begun to decrease this retrograde movement, and the tendency is today toward smaller, lighter and cheaper equipment with more frequent service. Early horse cars were models of light-weight construction. John Stephens, of New York, more than fifty years ago, built very light-weight street cars of the one-horse or "bob-tail" pattern. These cars frequently had bodies only 12 feet long and could seat 16 passengers, the total weight being not more than one ton. They were mounted on nicely designed trucks framed up with light iron forgings and malleable iron journal boxes and spring seats, were fitted with combination coil and rubber springs, and with 24 to 30 inch wheels of very light weight.

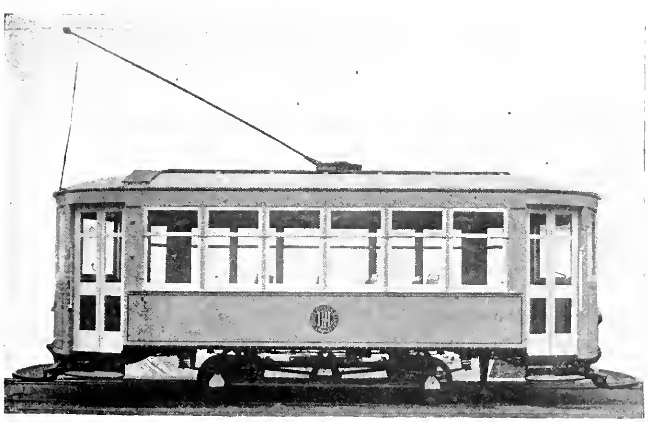


Fig. 1—One-Man Car and Feather-Weight Truck
Showing round ends, folding crank-operated doors and fender equipment.

The first attempt at electric traction was the mounting of motors on the old horse car trucks but, due to the lack of data as to the severe mechanical requirements,

such assemblies quickly rattled to pieces and improved constructions were found necessary. These failures were followed by heavier cars and trucks and, as the art of railway motor building grew, the weight of the cars steadily increased, limited only by the capacity of the motors which were commercially available to haul them.

FIG. 2—LIGHT-WEIGHT, ONE-MAN CAR
With plate steel sides. Mounted on roller-bearing truck.

One great factor in increasing the weight of street cars was the lack of engineering knowledge on the part of car builders and the prevailing method of constructing a platform floor system of sufficient cantilever strength to carry the body and passengers. Light weight and durable construction along this line was impossible. Then various subterfuges were adopted, such as "hog chains" and "over-trusses" with "composite sills" of wood and steel. These makeshifts greatly increased the weight, but did not increase the strength satisfactorily, and no proper solution was found until Thomas Elliott, in 1897, began to construct cars whose longitudinal stiffness depended upon the girder effect of sheet steel sides which replaced the old wooden sheeting and formed a girder of a width extending from the window rail to the bottom of the side sill and from corner post to corner post of the car.

FIG. 3—STEEL SKELETON FOR ONE-MAN, LIGHT-WEIGHT CAR
Showing plate girder sides and letter boards.

To keep pace with the calls for reductions in weight, low cost of construction and operation has required innovations and advances in the design, material and construction of car bodies, trucks and electric motors. The light-weight, one-man car is generally smaller than the ordinary single-truck car, although it usually seats more passengers than did the single-truck car with 20 foot body. The new car usually seats twenty to twenty-eight passengers and is from 25 feet to 30 feet long over bumpers. It should weigh ready for operation, not more than 9000 to 10 000 pounds. Such cars can be bought, complete with trucks and motors, for $2500 to $3000. The weight is distributed about as follows:—Body, 5500 pounds; truck, 2300 pounds; two motors, each developing about 30 horse-power, 800 to 900 pounds each. Chilled iron car wheels are now available weighing approximately 200 pounds each. The entire equipment has been refined, even down to the brake shoes, which weigh 13 pounds and cost 25 cents, compared with those of the old type, which weigh 30 pounds and cost 60 cents each.

FIG. 4—AISLE VIEW OF CAR
Showing cross seats, round top roof, fare box and the absence of bulkhead.

The truck design of the new cars has been worked out with coil springs operating in series with semi-elliptic springs, so that the riding qualities are superior to any single trucks heretofore marketed. Teetering is practically eliminated, due partly to the long wheel base, generally nine feet, and to the use of coil springs in series with leaf springs. Longer wheel base is permissible, because the submergence of flange on the 24 inch wheel in the guard-rail groove is shortened to such an extent that the nine-foot wheel base truck will round short-radius curves about as easily as the old seven-foot truck with 33 inch wheels. The improved riding qualities of these trucks are remarkable; in fact, these cars ride practically as well as the jitneys with which they compete.

Steel side car construction has reduced the thickness of the car side from 4 to 6 inches down to 1 inch or less, giving a corresponding increase in the aisle width ranging from 6 to 10 inches.

Coupled with the savings in power, track maintenance, wheel and brakeshoe wear by reduction of

weight, the economy of the light-weight, one-man car has been greatly increased by the simplification of the body and improvements in wearing parts. For instance, the doors have been so designed that no mechanism is required for their operation and the old-style hinges have been replaced by continuous, durable hinges of "piano-

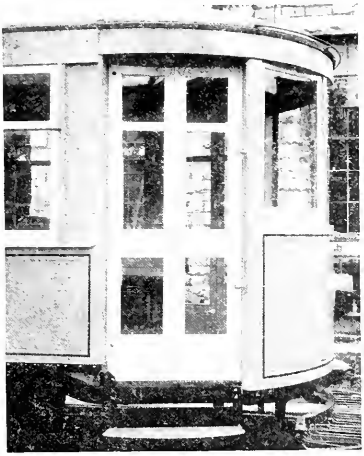


FIG. 5—CORNER DOOR OF CAR
Showing folding doors fitted with piano-box hinges and stationary step and drawhead.

box" construction, incidentally keeping out cold air and excluding dirt. The trucks have been so designed that the wearing parts are unusually accessible. An axle with wheels may be removed by simply loosening U-bolts from the journal boxes, while the brakeshoes may readily be replaced and adjusted by means of a single nut.

The light-weight cars for many cities or suburban routes are equally as fast in loading and schedule as are the two-man cars. For instance, with 500 volts at the trolley and a load of twenty passengers, an acceleration of 1.5 miles per hr. per sec. can be obtained. Assuming ordinary grades and six-second stops, the following schedule speeds can be obtained:—Five stops per mile, 11.4 m.p.h.; five and one-half stops, 11 m.p.h.; six stops, 10.7 m.p.h.; six and one-half stops, 10.3 m.p.h.; seven stops, 10 m.p.h.

The greatest economy of these cars is due to their light weight and the elimination of the conductor. In other words, the platform labor has been divided by two, as a rule, where one-man cars have been installed. There are, however, exceptions in some cities where the travel is usually very heavy on one end of the line for certain hours of the day. In such cases it is customary during such hours to put on a "swing run" conductor, who rides out to the first passing point and collects the fares, swinging over to the next car and returning to the starting point for another swing run. In some other cases where the car line runs through a city with a fare zone in the city and other fare zones at either end, it is occasionally essential to use a conductor to take up the fares in the middle zone, leaving the motorman to collect the fares from the passengers boarding the car in the outer zones.

In case of some eighteen cars operated under the direction of the writer on four street railway lines there was an approximate saving of $5 per car per day in platform expense. Under ordinary conditions, one-man, light-weight cars require a maximum of 0.75 kw-hr. per car-mile, as against 1.75 to 2.5 for the ordinary single-truck, two-man car weighing 10 to 15 tons. This saving in power at 1.5 cents per kw-hr. at the trolley wheel, and a mileage of 180 per day, usually amounts to $2 or $3 per day.

It has been found that the 200 pound, 24 inch chilled iron car wheels have two-thirds the life of the 600 pound, 33 inch wheels as a rule. That is, the wheel cost is reduced to approximately one-half, with a corresponding saving in rail wear and joint maintenance. Many recent improvements in light-weight, ventilated railway motors have reduced the cost of motor maintenance to less than half the former cost per motor mile. The 25 cent brakeshoes have been giving an average life of 7500 miles.

Actual records of claim departments show the percentage of miscellaneous accidents to have been materially reduced, while boarding and alighting accidents have been practically eliminated. Collisions with vehicles seem to have been reduced by reason of lighter weights and more quickly operated, high-efficiency brakes. New

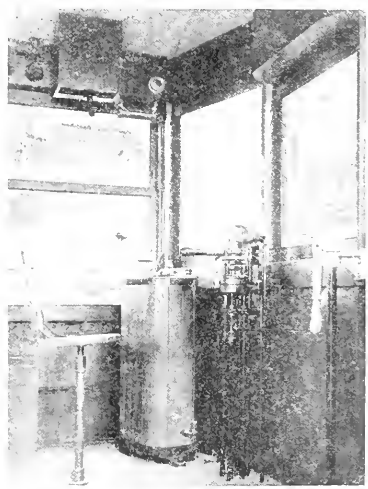


FIG. 6—VESTIBULE OF CAR
Showing motorman's seat and automatic or "deadman's" handle on controller for automatically cutting off power and applying brakes.

trucks have been developed with hand brakes which require practically no more labor to operate than air brakes or automobile brakes, as the brakes are applied with only half a turn of the crank handle, and a moderate pull on the brake handle is sufficient to skid the wheels.

The introduction of the steel side car, with the elimination of the bulk head and double sliding doors, together with the simplification of the trucks and wearing parts, has reduced car maintenance fully half. In other words, the light-weight, one-man car can be said to cost approximately one-half to operate, less than one-half for power, about one-half for platform expense, one-half for maintenance and one-half for accident expense. With such cars it is feasible to double the headway on streets, thus increasing the convenience to the public, with a resulting increase in traffic and at the same time keeping within the present limit of operating costs. This makes most effective competition for jitneys, as there is nothing equal to frequency of service for building up travel, especially in those cities where the traffic density is such that it is impracticable with the two-man, heavy-weight car to operate at less than 15 minute headway.

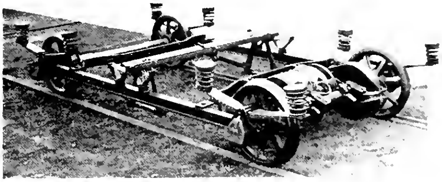


FIG. 7—FEATHER-WEIGHT TRUCK FOR ONE-MAN CAR
Showing "Wee" motor mounted, coil springs working in series with leaf springs and direct-brake rigging of simple construction.

The light-weight car is changing the economics of street railway construction, and some new railway projects which were not feasible heretofore will become profitable with such cars, for 50 pound rails can be used where previously 70 pound rails would have been required. There will be a corresponding difference in the cost of bridges, power stations, lines, etc. It is believed that these cars will be the salvation of many properties which are now in a precarious financial condition.

Notwithstanding the great advance in the art of car building there is still room for progress. At present the cost of a 24 passenger, 10 000 lb., single-truck, one-man, light-weight car with feather-weight motors is approximately \$2500 to \$3000. This is in sharp contrast with the cost of automobiles being used as jitneys. For instance, a Ford car costs, say \$365 complete, with its own motor and rubber tires. This great difference in the cost is, of course, due largely to the larger size of the electric car, but after making due allowance for size and weight the difference is very great and can be accounted for by the fact that automobiles of one design are manufactured by the hundred thousands, whereas electric railway cars are built to order in lots that average one dozen or less, almost every lot differing in size, design, truck arrangement, trimming, painting and the design of doors, platforms, roof, windows, seats, motors, wheels, axles and wiring.

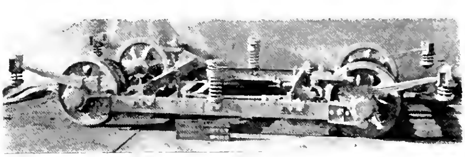


FIG. 8—CAR TRUCK
Showing extra long spring base and roller bearings on axles.

If tramway managers could see the importance of submerging their own ideas for special car designs and, through proper committees of engineers, agree on say three sizes or types of electric cars to be standardized by all builders, the cost of building cars would be very greatly reduced, and it does not seem impossible to expect that a small light-weight car might eventually be sold for one-half the present price.

The limitation of the car designs to a few standard sizes has equally great possibilities in the way of weight reduction and the improvement in details of construction. It should be easy to construct an electric car, which does not produce its own power, for running on rails that would weigh less than an automobile of equal carrying capacity, but the weight efficiency of even the best light-weight cars so far constructed is from one and a half to two times that of ordinary automobiles of equal capacity. Until these ideals shall have been approximated, it will not be possible to give that frequentcy of service or obtain the low cost of operation necessary to give the public and the electric railway stockholders the full benefits which should come from good service and reasonable profits on street railway investments. When such rolling stock becomes available there will be a great reduction in the expenditures necessary for track construction, track maintenance; also in cost of power houses, substations and lines, which at present have an average cost approximating \$1500 per car. With lighter and less expensive tracks, it is reasonable to expect that electric railway development will be pushed into new territory and that the public will be greatly benefited by the extension of fast car service.

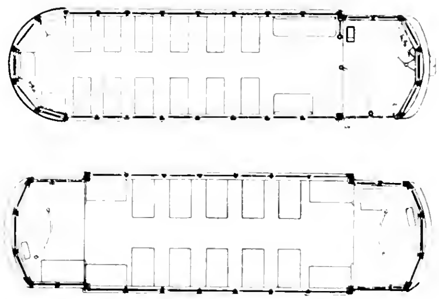


FIG. 9—PLAN VIEWS OF ONE-MAN, LIGHT-WEIGHT CARS
For one-way and double-end operation.

Toledo Adopts Train Control

C. A. Brown
Master Mechanic,
The Toledo Railways & Light Company

THE Toledo Railways & Light Company has been operating certain of its lines in the city of Toledo without a franchise since 1910, and the company has had trying experiences with municipal regulation, three-cent fares, etc., from that time up to the present. After several years of uncertainty as to the property's future status, during which the purchase of additional equipment had been necessarily deferred, the courts recently restored the five-cent fare and, out of the additional revenues made available, ordered set aside monthly a certain sum to be devoted to the acquisition of new rolling stock.

The local officers and the Henry L. Doherty management desired that the new cars provided for in the court decision should be of the most up-to-date construction and, as a preliminary to the final decision regarding the type of equipment, samples of three different cars borrowed from other companies were tried out in actual service in Toledo. The previous Toledo standard had been for several years the pay-as-you-enter type car with front and rear platforms. The cars seated 50 to 55 persons, weighed about 41 000 pounds without load, and were equipped with two Westinghouse No. 310-C motors. The first two cars borrowed for trial were also equipped with two motors and intended for single-car operation, but differed from the Toledo cars in that they were of the center-entrance type.

FIG. 1—TYPICAL PICNIC DAY SCENE

Suburban cars ready to leave city over the single-track line to Toledo Beach. Sometimes it is necessary to make use of some of the regular city cars on this line. On these occasions train operation is expected to materially assist in minimizing delays at sidings.

The third type of car borrowed for trial was obtained from the Cleveland Railways Company, and represented the most advanced practice in Cleveland. The car was equipped with four motors capable of hauling a trailer all day long, and the complete motor car and trailer unit was tested on the various lines in Toledo. The trailer was of the center-entrance type and had only the one entrance and exit. The motor car, however, had also a drop platform at the front end and was known as the "front-entrance, center-exit" type.* All passengers board the car at the front end and do not pay their fare until they pass the conductor's stand at the center of the car. This gives about half the car as a loading platform and enables the passengers to get aboard in much shorter time than if they had to pay fares before entering the body of the car. Some of the passengers take seats near the front of the car and do not pay their fare until they leave by one of the center doors. Others pay as they pass the conductor on their way to the rear part of the car and can then get off by the second center door without having to stop for payment of fare. The motor car seats about 54 and the trailer 60 people.

The success of this large capacity train unit, particularly in handling crowds from the factories and from the downtown district during the rush hour, and the economy in crew expense possible with the two-car train operation, led the Toledo Railways & Light Company to decide that their new cars should be of a similar type.

In the consideration of details of equipment it was brought out that as an alternative to the motor car and trailer scheme the equipment of each car with motors and control for independent or train operation offered certain advantages. Before the final decision was made the engineers of the Henry L. Doherty Company and the Toledo Railways & Light Company carefully investigated the relative merits of the two schemes and the following points were brought out:—

1—The motor car and trailer form of train unit first considered would give the necessary additional rush-hour seating capacity for the minimum first cost. The additional cost of a two-car multiple-unit train, as compared with the motor car and trailer unit, would be about \$850, or \$425 per car, for the particular type of equipment considered.

2—This two-car train unit, however, could be efficiently used only during morning and evening rush hours, and on holidays or other special occasions. The combined seating capacity of motor car and trailer would be about 110 people, which would ordinarily be much greater than the traffic requires. Therefore, during a large part of the day the trail car, representing about 37 percent of the first cost of the train unit, would lie idle in the barn.

3—During the non-rush hour part of the day it would be necessary to keep in service, on certain lines in the city, rolling stock that was comparatively expensive to operate, while half of the new cars, being trailers, could not be used economically.

4—On Sundays and special occasions during the summer the traffic on some of the suburban lines, particularly the Toledo Beach line (13 miles long), becomes so heavy that it is necessary to supplement the regular suburban equipment with some of the regular city cars. As the line is single track it sometimes happens that as many as four or five cars follow one another from siding to siding and, aside from the element of risk, there is a considerable delay at sidings awaiting for the last car to come up. This situation would be considerably improved by even partial multiple operation of trains of three to five cars.

*See article on "The 26 Inch Wheel, Low-Floor Cars in Cleveland," by Mr. Terrance Scullin, in the JOURNAL for October, 1915, p. 488.

5—Trailer operation involves four-motor equipment of such capacity that the most economical type of motor, the field-control type, could not be used unless the more expensive remote control were purchased. This was because no K controller of a suitable type had as yet been developed. The economy of field control in the Toledo service had been demonstrated by a sample equipment placed in service in 1914 Careful tests showed a saving in power of approximately 17 percent compared to the non-field-control equipment, with both equipments geared to give about the same free running speed. This large saving might not be obtained on the new cars, but it was estimated that the saving in power due to field control would be at least seven percent.

6—The combined weights of the motor car and the trailer would be less than that of the two-car multiple-unit train, but the weight of the single car with two motors would be less than that of the car equipped with four motors for hauling the trailer. Therefore, if two-car train operation were realized 100 percent of the time, the motor car and trailer would have the better weight economy, but any mileage made by the four-motor car operating alone would require additional power as compared to operating the two-motor car.

A careful study of these different factors led to the conclusion that the relative economy of the motor car and trailer as compared with the two self-propelled units depended altogether upon the percentage of time two-car operation would obtain. It was estimated that out of a working day of 16 hours there would be about six hours during which two-car trains might be operated economically. With this as a basis, a comparison was made of the power consumption of motor cars and

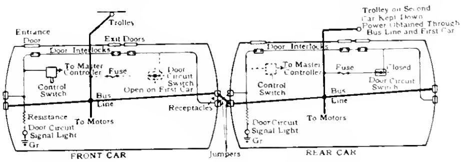


FIG. 2—SCHEMATIC DIAGRAM OF DOOR CIRCUIT OF TWO-CAR TRAIN

Power cannot be applied to the motors until all the doors of the car or train are closed.

trailers versus all-motor cars. It was assumed that the new motor cars would be operated all day, and that in the one case the trailers would be withdrawn during non-rush hours, and in the other case the two-car multiple-unit train would be broken up into twice as many one-car trains and some of the older equipment would be sent to the barn. It was estimated that under these latter conditions the saving in power alone would just about offset the additional fixed charges for the double motor train control equipments, and this, together with the savings in maintenance and the operating and other advantages mentioned, were considered important enough to justify the investment.

CONTROL EQUIPMENT

The control equipment of these cars is Westinghouse light-weight type HLF, arranged for single-end operation as a single car or in trains of several cars. It is also equipped with a bus line, so that all of the trolleys of a train do not have to be raised. Interconnected with the control system is a door interlock arrangement, which prevents a car or train from being started until all doors are closed, and also a rear light signal system which indicates whether the car is standing still, starting or moving.

The connections of the door interlock circuit are shown schematically in Fig. 2. The door circuit switch is closed only on the rear car, so that the current for the contact passes through all the door interlocks of the train in series to the master controller on the first car and thence to the control circuits. This arrangement allows the controller to be placed on the first notch as soon as the car stops, so that the car will start immediately when all the doors are closed. A signal light is also provided near the controller which, by lighting up, tells the motorman when all the doors are closed.

A slip ring is provided on the master controller which causes several of the important circuit-making switches to open simultaneously whenever the controller handle is moved one notch toward the *off* position. This distributes among several switches any burning that may occur when the controller is notched off, thus insuring a maximum life of switch contacts and arc box sides.

The connections of the rear signal light system with the main circuits are shown in Fig. 3. When the car is standing still the circuit is completed through a red light by the resistance which shunts the No. 2 motor fields. This resistance is high in comparison with the

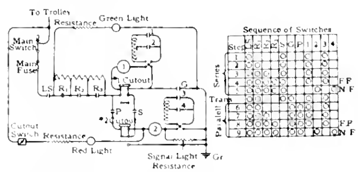


FIG. 3—SCHEMATIC DIAGRAM OF MAIN CIRCUIT AND REAR-END SIGNAL LIGHT ON TOLEDO CARS

At standstill the red lamp burns brightly and the green lamp is out. On the first notch the green lamp lights up and stays lit as long as power is on. As the main resistance is cut out the red light becomes dimmer; at the full series position it gets half voltage; at full parallel it is shunted out by the main circuit.

resistance of the motor field and, therefore, does not interfere with the normal operation of the motors. During series running a green light burns also on account of closing the *LS* switch. During parallel running the potential across the red light is reduced to zero, which extinguishes the red light, but the green light, being directly across the line, still burns.

The brake equipment is of the Westinghouse straight air type with an automatic emergency feature, by means of which the flexibility and simplicity of the straight airbrake is retained for ordinary service operations, with the additional protection afforded by the automatic application of the brake in the event of ruptured piping. The factor of safety is still further increased by making it possible for the conductor to set the brakes in emergency, if conditions require, through a conductor's valve.

The motor-driven air compressor is of the "bungalow" type, of which the most pronounced features are low overall height, light weight, accessibility and large

capacity of the motor. It is suspended from the car underframe by a special light-weight suspension of the three-point type, which makes for ease of mounting and dismounting from the car. The compressor governor is of light weight, compact and simple design. An emergency valve operates to apply the brakes automatically should the emergency line become ruptured from any cause or should the conductor open the conductor's valve. It has a sanding feature whereby sand is automatically applied to the rails during emergency applications. The remainder of the equipment includes the usual brake valve, main reservoir, air gage, etc.

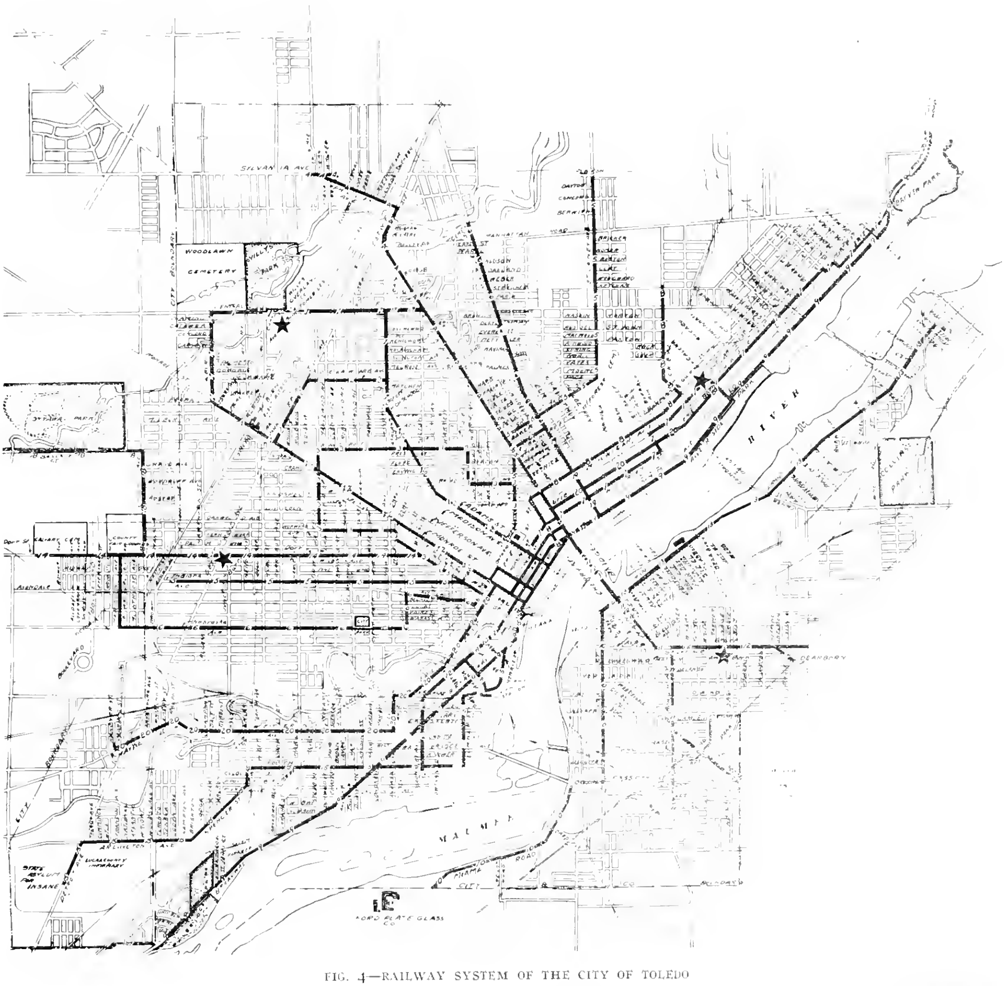


FIG. 4—RAILWAY SYSTEM OF THE CITY OF TOLEDO

Number	Name of Line	No. Cars Operated		Headway		Mileage	Number	Name of Line	No. Cars Operated		Headway		Mileage
		Normal	Rush	Normal	Rush				Normal	Rush	Normal	Rush	
1	Long Belt	10	14	10	7 5	7 175	11	East Broadway	[illegible]	8	8	[illegible]	[illegible]
2	Short Belt	8	10	10	7 5	5 306	12	Starr & Maumee	5	6	12	11	4 [illegible]
3	Bancroft Belt	8	10	9	7 5	4 985	13	Ironville Line	5	[illegible]	12	[illegible]	1 [illegible]
4	Cherry & Union Depot	12	19	6	4	4 939	14	Dorr Street Line	7	10	[illegible]		[illegible] 785
5	Indiana & Stickney	12	12	11	7 5	6 332	15	South Street Line	6	7	11	10	5 205
6	Nebraska & Lagrange	8	11	11	8	6 05	16	Woodville Line	1	1	15	15	0 635
7	Huron Line	5	6	11	10	4 251	17	Long Belt Cross Line	1	1	10	10	0 [illegible]
8	Michigan Avenue	2	2	20	20	2 572	18	Ottawa Park Line	1	1	30	30	1 [illegible]
9	Summit & Broadway	12	17	8 5	6	8 335	19	Lagrange Short Line	1	1	30	30	1 620
10	Oak & Union Depot	6	11	12	6	5 052	20	Erie & Western	[illegible]	12	10	7 5	5 [illegible]

Operation, Maintenance and Performance of Storage Battery Cars

ON THE LONG ISLAND RAILROAD

R. W. Brodmann
General Foreman Electrical Equipment,
Long Island Railroad Company

IN SEPTEMBER, 1914, two storage battery cars equipped with multiple-unit control were placed in service on a short connecting line of the Long Island Railroad, known as the New York Bay Extension, between the towns of Mineola, on the main line, and Valley Stream, on the Montauk division, both important junctions on the Long Island System. This branch line is 7.3 miles long, has six intermediate stations, and was formerly operated by steam. Nine round trips constitute the daily schedule, and connections are made at both terminals with the main line trains. The running time is 23 minutes. Both of the above-named towns lie within the electrified zone, yet the branch line was not electrified; hence the selection of storage battery cars. The third-rail voltage in the electrified zone is approximately 675 volts and, as the cars require but 415 volts for charging, a resistance was mounted on each car in connection with suitable switches and portable jumper, by means of which the cars could be charged anywhere where third rail was available. This rather unique self-contained arrangement eliminated regular charging stations and made the cars available anywhere within the electrified zone. The jumper is a flexible, well-insulated cable, fitted at one end with a standard head that fits into a receptacle on the car body, while a prong-shaped contact with suitable handle is provided on the other end. This prong is thrust against the third rail.

R. W. Brodmann

CAR BODIES AND TRUCKS

There are two types of cars, one for passengers only, and the other a combination passenger-baggage car. Both cars have the same dimensions and the same design of steel underframe. End doors are provided in the vestibules to enable multiple operation, but body end bulkheads are omitted.

The bodies are 32 ft. 0 in. long over platforms 8 ft. 4 in. wide, and are mounted on Continental type single trucks, with a 12 ft. wheel base. Standard M.C.B. 4.5 x 8 in. journals and 30 in. wheels are used, and the car complete with equipment weighs 28 000 lbs. Seating capacity of passenger car, 32.

ELECTRICAL EQUIPMENT

As the cars were intended to be operated either singly or in multiple as a train, as traffic demand, Westinghouse multiple-unit control, PK type, was installed. This equipment consists of a main or motor controller with PK attachment, mounted on a platform; limit switch and overload relay are placed overhead on the same platform. The line switch and resistors are underneath the car, and a master controller mounted on each platform. The control wires terminate in a standard seven-point receptacle at each end of the car, and by means of a single seven-point jumper between the two cars multiple operation can be obtained from any master controller on the train. All control and power wiring is installed in conduit, terminating in suitable junction boxes, according to established standards used on the large third-rail equipment operated by this company. Many of the control parts are also interchangeable with similar parts used on the larger cars, thus minimizing the number of repair parts to be carried in stock.

There are two 20 hp, 250 volt, Type 65-A3, ball-bearing motors per car, one geared to each axle. These motors are also of Westinghouse make, and specially designed for this service, field control being used to reduce the heavy current demands while starting. The motors are water and dust proof and, on account of their small size, are easily accessible for inspection.

AIRBRAKE SYSTEM

Westinghouse "Featherweight" type airbrake, with automatic feature, is used. Each car is equipped with a motor compressor, mounted under the car, a synchronizing governor and a pneumatic pump switch placed overhead on No. 2 platform, and the necessary engineer's valves, brake cylinder, reservoirs, etc., in their respective places. The train pipe is carried to each end and fitted with standard hose and coupling for multiple operation. The automatic feature is obtained in connection with the master controller. Contacts are provided so that if the motorman takes his hand off the handle it returns automatically to the central position, and a magnet valve, controlling the train brake relay valve, is energized, the relay is opened and the brakes are automatically applied.

STORAGE BATTERY

The passenger car has a battery of 224 Edison A-H-4 cells; 219 of these are used for power; the remaining five are used for the lighting system, the compressor synchronizing circuit and the electropneumatic signal

whistle. The air compressor and the PK control are operated from the power battery. The batteries are placed under the seats and insulated by means of special glass insulators. The power battery in the combination car consists of 231 cells. This is due to more space being available, as the baggage compartment extends to the end of the car, the platform being eliminated, and the master controller, etc., being mounted in the baggage compartment.

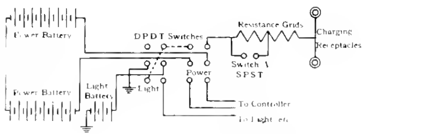


FIG. 1—DIAGRAM OF CHARGING CIRCUITS

The battery is rated at 150 ampere-hours and, by means of a single-pole, single-throw knife switch, mounted in a cabinet at No. 2 end of car, the battery can be charged either at a 70 ampere or 35 ampere rate, as conditions demand. The light batteries, when requiring charge, are connected in series with the power battery. Fig. 1 is a diagram of the charging circuits. The two double-pole, double-throw knife switches are also mounted in a cabinet on No. 2 platform. The cars receive a regular four-hour charge every night. This is done by the substation operator at Valley Stream, who also flushes the batteries and keeps them clean. During the day, when cars are in service, the motorman charges the batteries at both terminals during lay-overs.

AUXILIARY EQUIPMENT

The lighting system consists of 14 six-watt, six-volt Mazda lamps, and the headlights, which are of the Golden Glow type, are provided with 36 watt, six-volt concentrated filament lamps. Both air whistles and foot gongs are provided for crossing signals.

INSPECTION AND MAINTENANCE

A repairman from the company's main shops at Morris Park is sent to Valley Stream weekly to inspect these cars and make all necessary repairs and adjustments. A small car barn, with pit, is located at Valley Stream for the accommodation of these cars, and one car is placed over the pit and inspected, while the other maintains the service. When the first car is inspected the cars are exchanged and the other car is taken in for inspection. In this manner it has been possible to take care of the equipments without interruption of service.

Should the cars require extensive repairs, such as replacing wheels, or body repairs, that cannot be handled by the inspector, the cars are brought to the Morris Park shops by the crew at the end of the day's run, a distance of 8.5 miles over the Montauk division, under their own power. The cars are brought to the shops once a year for a general overhauling, when the bodies are painted and equipment thoroughly overhauled. In this manner it has been possible to keep the equipment in first-class condition without interruption of service.

FAILURES

During the two years of operation failures have been few, and of no serious nature. Below is a list of the failures and their causes:—

No. of Failures	Cause
1	Line switch interlock loose, due to locknut coming off.
1	Loose resistance lead, due to locknut coming off.
1	Compound used for sealing contact plates on reverser drum in controller, becoming soft and running over the contacts.
1	Broken control cutout switch blade.
1	"On" magnet coil in controller short-circuited.
1	Poor tension on controller finger, failing to cut out resistance in motor circuit.
1	Charging jumper receptacle pulled off, attendant failing to remove jumper before starting car.
3	Pilot governor inoperative, due to pipe scale on valve seat.
4	Brake relay valve stuck open, due to pipe scale on valve seat.
1	Defective fuse (refillable type) in control circuit.
1	Broken resistance grid, due to striking obstruction.
2	Broken charging resistance, due to striking obstruction.

Several failures not listed above were caused by battery containers being grounded to underframe of car, due to careless flushing of batteries, and on one occasion where car was being charged during a severe rainstorm with windows open. On several occasions trouble was also experienced due to battery being insufficiently charged. These should be considered as man failures. A recent inspection of the electrical equipment showed it to be in excellent condition, with practically no signs of wear. The controllers, line switches and motors appear as if they had just come from the factory, and the battery on a recent test showed 115 percent of normal capacity and mechanically intact. The solution in the batteries has been renewed but once and the present solution is still good for some time. The airbrakes have likewise given no trouble.

TABLE I—RELATIVE COSTS—1915

Equipment.	Two Multiple-Unit Battery Cars.	1 D 53 Locomotive 1 Pass.-Bagg. Car
Investment.	$20 535 02	$11 683 92
Interest at 5 percent	1 026 75	584 17
Depreciation	1 117 64	350.49
Maintenance	755 44	2 304 81
Handling coal, engine-house expense		
Water supply.		1 322 93
Crew costs	3 485 46	7 886 54
Supplies	36 58	63 00
Cost of power or coal.	1 309 76	4 790 80
Labor for charging or oil	753 30	41 27
Instrument work.	38 70	
Total costs	$ 8 523 63	$17 344 01
Cost per train-mile	0 3928	0 7933

COMPARATIVE COSTS

The relative costs of operation for the year 1915 are given in Table I. The figures for electric service are actual; those for steam service are estimated. The steam

service formerly operated was never more than one-third the present schedule, as the traffic then did not warrant the expense.

In estimating the depreciation chargeable to cost of operation, the following percentages were taken:—Three percent for car body, ten percent for storage battery, four percent for electric equipment, and three percent for locomotive. The crew required to operate this service with electric equipment comprises a motorman and conductor; for steam service, an engineer, fireman, conductor and a flagman.

CONCLUSION

At present a single car is sufficient to handle the traffic most of the time. The work is then divided between the two cars. No trouble, however, was experienced when a single car was called upon to handle the entire service for week intervals when the other car was not available for this service. In such cases the night charge is increased slightly. A typical current consumption sheet for 24 hours is given in Table II.

TABLE II—CURRENT CONSUMPTION SHEET

CAR No. 2

Time of charge	Rate	No. of Single trips	Amp-hr dis-charge	Amp-hr before charge	Meter after charge	Amp-hr. charge
Night.	Low		.	50	205	145
12:20– 1:00	Low			205	165	40
5:25– 5:50	High	4	85	250	220	30
6:43– 7:00	High	2	40	260	245	15
		2	40	285		..
Total..			165			230
CAR No. 4						
Night.	Low			60	205	155
8:15– 8:40	High	4	85	290	265	25
9:15–10:40	Low	2	40	5	135	70
12:25 1:00	Low	2	35	270	240	30
		2	40	280		
Total .			200			280

		Car No. 2	Car No. 4
Total car miles per day..	130	75	55
Total single trips per day ..	18		
Max. number of passengers on any one trip . ..	30		

Emergency Braking of Direct-Current Electric Vehicles

J. A. CLARKE, JR.

IT IS as natural for a motorman to "reverse" his car when it is getting beyond control as it is for a man to change his mind when he finds his actions are leading to certain calamity. A steam locomotive engineer will do the same thing. The electrically-propelled vehicle, however, has the advantage that it can be braked by means of its propelling motors. This advantage is due to the fact that a dynamo-electric machine designed for use as a motor may, if properly excited and connected, be used as a generator. While this fact is generally understood, the principles involved and the successive actions produced in using the motors as generators for the purpose of stopping a railway car have often been misinterpreted. A simple outline may be of interest and serve to explain the various methods used in employing these principles in practical service.

THE most common method for securing an emergency dynamic brake is to connect a pair of motors in parallel, cut them off from the line and reverse their field connections. With a 600 volt, four-motor, series-parallel control equipment, where two motors are permanently connected in parallel, it is merely necessary to operate the reverser. With a 600 volt, two-motor equipment, or a 1200 volt equipment using two motors in series, it is necessary to turn the controller to the parallel connection as well as to reverse their fields.

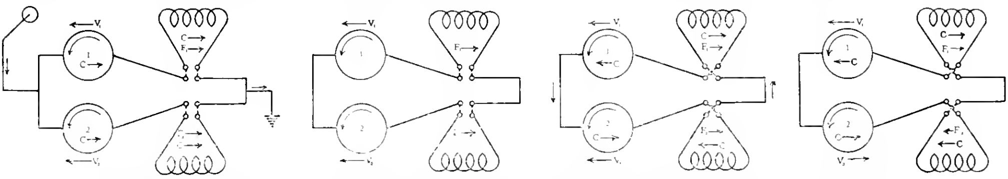
J. A. CLARKE, JR.

With most remote types of control, using a separate drum for the control of the reverser, it is necessary to move the main handle of the master controller to the first notch as well as to operate the reverse handle. With two-motor equipments, it is necessary to move the main handle to the first parallel notch. After the emergency brake has been applied the reverse handle should not be touched again until the car comes to a full stop.

The actions of a pair of motors when changing from running to braking conditions are shown in Figs. 1 to 6. For simplicity, the motors are considered as permanently connected in parallel. The arrows indicate directions of armature rotation, current flow, armature voltage and the field produced by the main field coils. The armature voltage V is the counter e.m.f. of the machine when acting as a motor, and its generated voltage when acting as a generator. The field F is the actual field produced by the current flowing in the main field coils or the residual field when no current is flowing. Figs. 1 and 2 show the conditions for normal running and for coasting, respectively, the two stages immediately preceding the manipulation of circuits required to produce dynamic braking. Fig. 3 shows the conditions which exist immediately after the field connections of the two machines are reversed. These conditions continue only for the very brief space of time

during which the residual field in No. *2* machine is being brought to zero by the action of the current flowing in its main field coil. It is assumed that the residual field of the No. *1* machine is slightly stronger than that of the No. *2* machine, so that the No. *1* armature builds up more rapidly than the No. *2* armature and forces current to flow as indicated. It will be noted that this direction of current flow is such that it tends to strengthen the field of the No. *1* machine and to weaken the field of the other machine. During the short period illustrated by Fig. 3 the No. *1* machine runs as a generator driven by the momentum of the car and will operate the No. *2* machine as a motor, which tends to propel the car in the original direction. The kinetic energy of the car, due to its velocity, will be reduced an amount equal to the work required to generate the current in No. *1* machine during the time this condition exists plus the energy required to overcome bearing friction, windage, etc.

The current in the No. *2* field will quickly reverse the residual field and build up a field in the opposite direction. This will reverse the armature voltage V_2 and cause No. *2* machine to run as a generator. These conditions are shown by Fig. 4. Both machines are now running as generators in series connection, short-circuited on themselves and both generating current in the same direction. This effect is cumulative, and an excessively heavy current will tend to flow. The force required to produce this current will quickly reduce the velocity of the car.



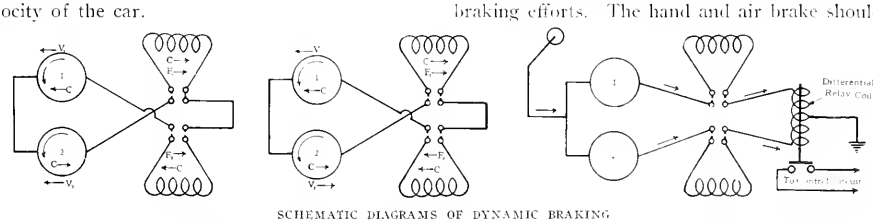
SCHEMATIC DIAGRAM OF MOTOR AND FIELD CONNECTIONS SHOWING SUCCESSIVE STEPS IN DYNAMIC BRAKING

Fig. 1—Normal running. Fig. 2—Coasting. Fig. 3—Preliminary braking. Fig. 4—Final braking.

Another method for producing the dynamic braking circuit is to interchange the fields of the two motors instead of reversing them. This method is especially adaptable to a two-motor equipment where some special switch must be used to connect the two motors in parallel. The first two stages in this case are exactly the same as Figs. 1 and 2, except that the two motors are not connected together as in Fig. 2, but coast in open circuit. Fig. 5 shows the conditions existing for the short period immediately after the fields of the two machines are interchanged, and Fig. 6 shows the final conditions which tend to bring the car to a stop. It is assumed here also that the No. *1* machine is the stronger at the start. The results produced are the same as explained for the previous arrangement, as can be easily seen by comparison of Figs. 3, 4, 5 and 6.

It should be kept in mind that these braking schemes are for use in emergency only and should never be used for regular service stops. The current which flows while the two motors are running as generators on short-circuit is many times the hour rating, and it builds up so rapidly that in many cases the machines flash at their commutators. In addition, the gears, pinions and armature parts are subjected to excessive mechanical strains. This method of braking should only be used to prevent loss of life or material property damage.

To keep the dynamic braking current within safe limits, resistance is sometimes inserted in the motor circuit at the time the braking connections are made. This not only reduces the possible damage to the motors, but assures a smoother, lighter braking effect. An excessive current causes the machines to stop suddenly, so that the wheels will slip for an instant and the generator action will cease. The wheels will then start to roll again, and the braking action and slipping of wheels will alternate as long as the wheels tend to slip. This same action takes place when using emergency braking on a bad rail, the wheels alternatively slipping and rolling and the car being subjected to a succession of short braking efforts. The hand and air brake should be released in such a case, as they will grip the wheels, prevent them from turning and the car will skid continuously.



SCHEMATIC DIAGRAMS OF DYNAMIC BRAKING

Fig. 5—Preliminary braking. Fig. 6—Final braking. Fig. 7—Differential relay scheme.

With the ordinary K-type platform controller, both the main controller and the reversing drum are under the direct control of the motorman and emergency dynamic braking is always available. A multiple or remote control equipment, using storage battery current for the control circuits, is also under direct control of the motorman. An electro-pneumatic type of control

using line current for the control circuits can be conveniently equipped with an air valve mounted on the car platform and piped so that the reverser can be thrown directly by air. With a straight electric type of remote control some direct mechanical means must be used to operate the reverser from the car platform on account of the probability that the trolley will be off the wire at the time the emergency brake is most needed. This method is sometimes used with electropneumatic control where it is desired to have the emergency brake entirely independent of air pressure as well as of trolley voltage.

Since reversing switches are not equipped with blowout coils, the dynamic-braking circuit, once established, should not be interrupted until after the car comes to a full stop. Many reverser drums are damaged and often destroyed due to neglect of this precaution. This source of trouble is more common with remote control equipments on account of the greater distance separating the reverser and the motorman. Although a dynamic-braking circuit may be safely interrupted on a two-motor, series-parallel control equipment by returning the main handle to the "off" position, and thereby breaking the dynamic current before operating the reverser, it can never be done on any equipment where pairs of motors are tied permanently in parallel, as is the case with any standard 600 volt, four-motor, series-parallel equipment.

Any air-operated or mechanical system for emergency operation of the reverser of a remote control system should be arranged to cut off the trolley current from the control circuit and lock the reverser in its new position until the car comes to a full stop. A mechanical device for this purpose, actuated by the emergency operation of the reverser, mounted underneath the car body, makes it necessary for the motorman to get off the car to reset it.

Another scheme of control is shown by Fig. 7. Here a differential current limit relay has its two coils so located in the motor circuit that they will buck each other during normal running, but will add when the dynamic-braking current is flowing and hold the control circuits open. This gives the motorman control of his reverser as soon as the car has stopped and makes it unnecessary for him to leave the car platform.

The simplest emergency dynamic-braking scheme is usually the best, as little is to be gained by the addition of complicated devices to the car control system. It is unwise to arrange the controlling mechanism so that it can be operated simultaneously by several members of the train crew, if such an arrangement permits their combined efforts to balance and produce no effective results. It may be disastrous if it takes complete control of the car out of the hands of the motorman. When laying out the mechanism for operating an emergency braking system, a careful study should be made to secure the simplest arrangement which will take care of the possible conditions to be met in actual service. By the strict observance of this precaution, confusion in operating will be eliminated and an emergency can safely and quickly be handled when it does arise.

Unit-Switch Control on the New York Municipal Railway

E. Keller

EFFICIENCY as applied to electric traction has been given careful thought and study during the past decade by operating officials and by the various manufacturers of railway equipment. The minimum power consumption per seat-mile which all operating men are seeking has been approached largely through three major factors:—

1—The recognition of the value of coasting.

2—The reduction in weight of car body and equipment.

3—The field-control motor, saving rheostatic losses.

The installation of tungsten lamps and thermostats for regulating power heating have also resulted in a saving of power.

Possibly greater savings have been effected by the revised designs of control equipment than in any other one way.

After careful analysis by the board of engineers, a type of control was selected for the new subway cars of the New York Municipal Railway Corporation which embodies all the desirable features of simplicity, durability, accessibility and lightness. This type of control,

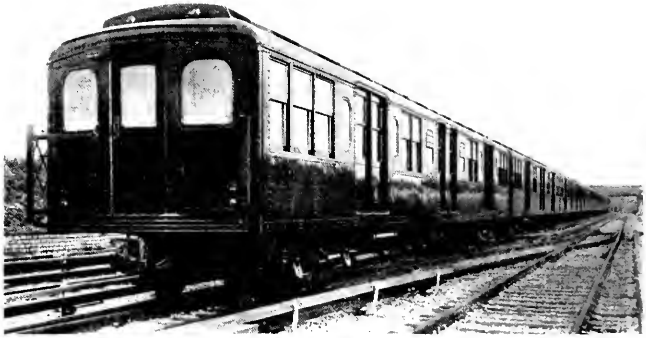


FIG. 1—SIX-CAR TRAIN ON THE NEW YORK MUNICIPAL RAILWAY
Equipped with unit-switch control.

which is known as the 214, is a combination of the well-known HL and PK types. The control unit is completely self-contained, as shown in Fig. 3, and includes six electropneumatically operated switches which control the series, bridging and parallel connections of the motors; a line switch; a reverser, and a separate compartment for housing the PK drum which governs the rheostatic and field-control connections.

A new and valuable feature of this control is that selective acceleration is obtained, i. e., the current input is determined by the load in the car. To the empty and load-actuating device of the brake system* is attached a rheostat, which operates in the following manner:—

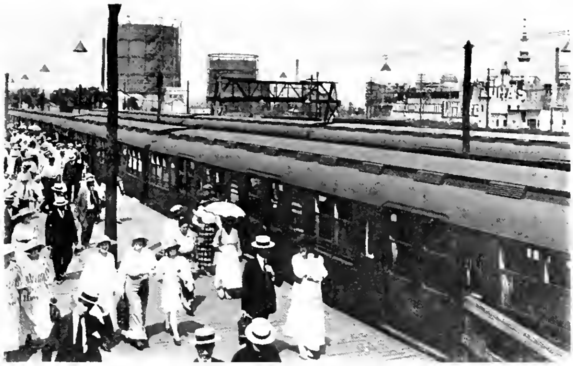


FIG. 2—PASSENGER STATION OF THE NEW YORK MUNICIPAL RAILWAY AT CONEY ISLAND

The series limit switch of the control has a compound winding, one coil of which is connected in the motor circuit, while the other coil is wound in opposition to the first coil and connected to the battery through a variable resistance. The movement of the arm of the rheostat which controls this variable resistance is governed by the load in the car, and the current in the secondary coil of the limit switch thus varies with the load. With the maximum load on the car all resistance is cut out of the secondary circuit and the range of operation of the limit switch is thereby automatically reached. With light load, as with the car empty, no current passes through the secondary coil.

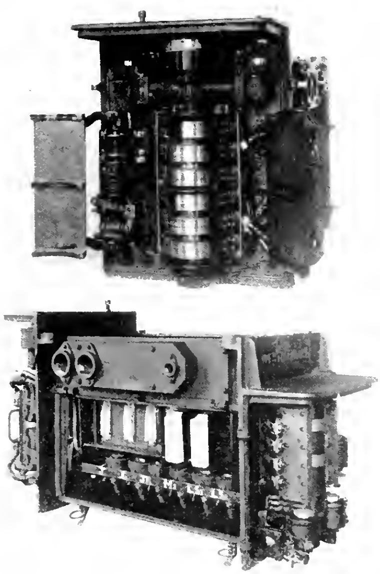


FIG. 3—MAIN CONTROL BOX
The *PK* drum shown at top governs rheostatic and field control.

The functions of a controller are of two kinds. The first or major duties consist of connecting the motor in series, bridging and parallel, and are performed in the 214 control by electropneumatic switches; while the second or minor duties, such as rheostat and field control connections, are performed by a small drum-commutating switch operated by a rack and pinion. By using the commutating switch instead of a group of unit switches, a simpler, smaller and lighter group is secured without lessening its effectiveness. The switch group, which is designed to handle two 200 hp motors, weighs 900 pounds—scarcely more than half the weight of the former control outfit of similar capacity. But five conduit pipes are used for the motor and resistance circuit, the former using multi-conductor, five-wire cables, permitting a low cost of installation.

FIG. 4—CAR VESTIBULE
Showing mounted controller.

The successful operation of the low-voltage train line for electropneumatic control throughout the country

*See article on "Recent Developments in Airbrakes," by Mr. H. C. Donaldson, in the JOURNAL for October 1915, p. 467.

has resulted in its adoption in other fields. Heretofore the battery served only the control, whereas on the New York Municipal cars its use has made possible a more reliable and extended operation of the airbrakes, the side-door machines, the emergency, marker, tail and indication lights and the buzzer signals. The door machine magnet valves are standard and are interchangeable with those of the control.

FIG. 5—MASTER CONTROLLER
Housing both control and auxiliary switches.

The selection of a proper battery and suitable means of charging it was given careful thought and study. The former practice consisted of having two sets of insulated batteries per car, which were charged either from the car lights or with current shunted from the compressor. The chief disadvantage of this arrangement lay in the fact that it required the changing of the battery switches each day which, when neglected, resulted in excessive overcharge and discharge. The new arrangement provides but one set of 32 volt Edison batteries per car, which are connected to the negative side of the compressor, thereby permitting them to float on the line with a permanent ground connection on one side. In order to distribute the load equally, the batteries throughout the train line are connected in parallel.

Seven train line wires are used for the control, and in order to secure operation or to maintain main current on the equipment it is necessary to establish a common connection for three wires. This provides an exceptionally safe train line, even with the control supply circuit grounded. Should the necessity arrive, the motor can be bucked by opening the line relay cutout switch, which renders the line switch inoperative, and is comparable to opening the circuit breaker on a car equipped with drum control. The master controller must then be reversed and advanced to the multiple position in the usual manner.

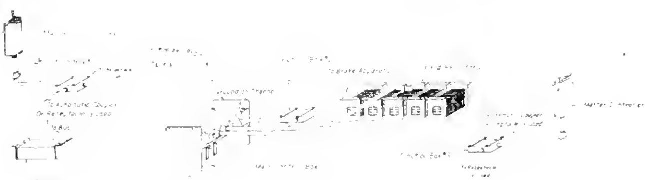


FIG. 6—SCHEMATIC CAR LAYOUT OF CONTROL EQUIPMENT

In order to secure the maximum compactness, the master controller was designed to house both control and auxiliary switches, as shown in Fig. 5. On the right-hand side the control cutout, circuit breaker reset, line relay cutout and marker light switches are located. The brake supply switch and connection board are located at the bottom.

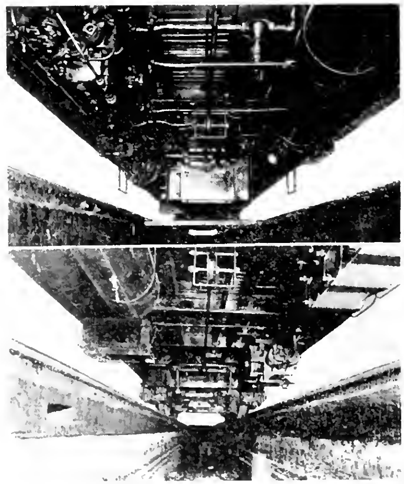


FIG. 7—TWO VIEWS TAKEN FROM REPAIR PIT
Showing under-car equipment.

The cars are all equipped with Westinghouse automatic electric couplers. The train line, consisting of 18 wires, terminates in a receptacle beneath the coupler, thereby eliminating the customary train line receptacles and jumpers with their incidental troubles. Positive contact is secured at the connections in the electric coupler, which, with well-designed low-current magnet valve coils in the control, has made possible the operation of a 16 car, all-motor-car train, exceeding anything previously attempted in railway equipment.

An evidence of the reliability of the control is shown by the mileage between inspections, which is now 2000 miles instead of on the usual 1000 mile basis. The control has been in extensive subway service, and the results obtained have shown that marked economies in maintenance are secured.

Standardized Car Equipments for New York Dual System of Rapid Transit

Lynn G. Riley

THE new subway and elevated electric railroads now being built in New York City, when combined with the present transportation system, will provide the most complete and expeditious urban transportation system in the world. The extent of this system is shown in the following extract from a recent report of the Public Service Commission for the First District of New York:—

"The new project is known as the 'Dual System of Rapid Transit,' and includes both subway and elevated constructions. The existing rapid transit lines, which will be embraced in the new system, have 296 miles of single track. The dual system will have 618 miles of track, and will increase the transportation facilities in even greater ratio. When completed, the new lines will be combined with the existing railroads, and will be operated in two grand divsions, one by the Interborough Rapid Transit Company, and the other by the New York Municipal Railway Corporation.

"The Interborough Rapid Transit Company will operate the following divisions:—

Existing subway lines	73 miles
Existing elevated lines	118 miles
New subway and elevated lines, constructed jointly by city and company	146.8 miles
Elevated extensions, reconstructed by company	10.4 miles
Third-track additions to elevated roads, constructed by company	10.5 miles
Total track-miles	358.7 miles

"The New York Municipal Railway Corporation will operate the following divisions:—

Existing B.R.T. elevated lines	105 miles
Subway and elevated lines, constructed jointly by city and company	110.4 miles
Elevated extensions, constructed by company	35.3 miles
Third track and reconstruction	9.3 miles
Total track mileage	260 miles
Grand total for the dual system	618.7 miles

"At present the existing rapid transit lines (not including the portions of the new system which are already in service) are carrying about 800 000 000 passengers per annum. The dual system, when completed, will be able to carry more than 3 000 000 000 passengers in the same period of time."

GENERAL CHARACTERISTICS OF NEW CARS

The new steel cars being used by the Interborough Rapid Transit Company weigh approximately 38 tons fully equipped, and are driven by two 170 hp motors. The subway trains are regularly made up of five or six cars, including two trail cars, and during the rush hour trains consist of from eight to ten cars, including three trail cars. The additional elevated cars are all motor cars, reconstructed from the older cars used in the subway. They are equipped with two 115 hp motors, and trains are made up entirely of motor cars. The balancing speed of these equipments is approximately 40 miles per hour, and a schedule speed of 15 miles per hour in local service, and 25 miles per hour in express service is maintained.

The all-steel cars on the system operated by the New York Municipal Railway Corporation are somewhat larger, being 67 feet long overall, with a capacity of 280 passengers, and weighing 42 tons equipped. The equipment consists of two 170 hp motors, and the balancing speed is approximately 50 miles per hour.

THE BASIS FOR STANDARDIZATION OF CONTROL

In providing rolling stock for the new systems there have been purchased more than 1300 motor car equipments, and in view of the vast extent of the system every effort has been made to have all control equipments conform to certain well-defined standards. The following features are considered to be of prime importance:—

1—Low-voltage train line circuits instead of 600 volts.

2—Electropneumatically operated control apparatus for all power circuits.

3—Combinations of apparatus to secure minimum weight.

4—The use of the common low-voltage battery supply for the operation of electric brakes, signals and all other auxiliary apparatus.

5—Duplicate standardized parts for elevated and subway equipments of different capacity.

6—Combination of all control and auxiliary train line circuits in a single automatic electric coupler.

7—Provision for the ultimate application of regenerative braking.

In choosing the low-voltage train line system in preference to the 600 volt system the following advantages were considered:—

1—Continuity of the control supply independent of the power supply on the leading car in the train.

2—Uninterrupted current supply for the operation of electric brakes and for signals, marker lights and other auxiliaries, including door engines.

3—Ability to reverse the motors in an emergency, after power has failed.

4—Freedom from deranged control circuits, due to less liability of grounding and arcing from point to point in the couplers.

5—Inspection and testing may be carried on without applying power to the car.

6—The design of detail apparatus connected with the equipment is simplified and cheapened by being adapted to low voltage.

The advantages to be derived from the use of pneumatically-operated motor control apparatus have been clearly demonstrated in all classes of service throughout the world. The general principle of utilizing power which is available locally on each car, rather than to transmit all operating power from the front car of the

train, insures reliable and positive operation. The control circuits act only as relays in transmitting the desire of the operator to the individual car. Air pressure is always available, and has been found to be a very flexible and efficient means of setting up contact pressures, making and breaking power circuits, and manipulating various classes of drum-type switches. Adequate power may be concentrated in a small space, and the inherent cushioning effect of compressed air obviates all sudden strains and shocks in the apparatus, and insures long life of the wearing parts.

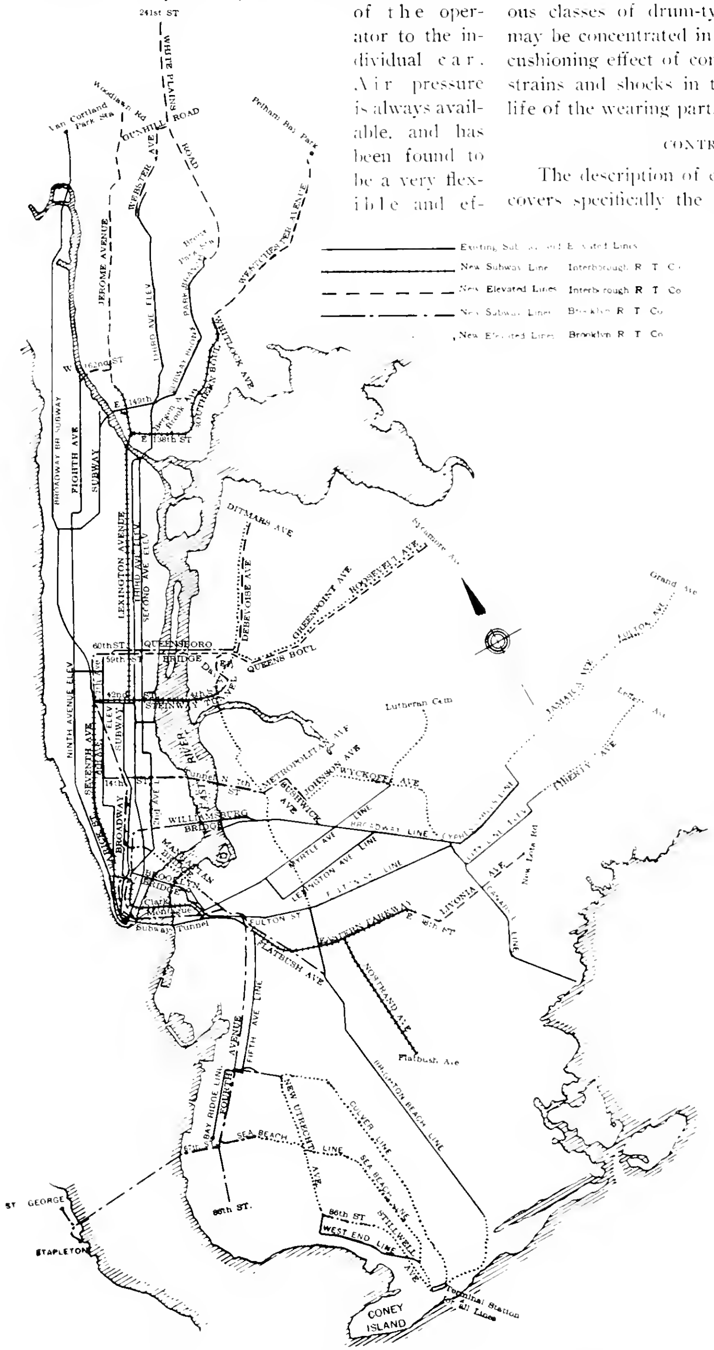


FIG. 1—SKETCH OF NEW YORK CITY DISTRICT SHOWING DUAL SYSTEM OF RAPID TRANSIT

CONTROL APPARATUS

The description of control equipment which follows covers specifically the 515 equipments supplied to the Interborough Rapid Transit Company by the Westinghouse Electric & Mfg. Company for use on both subway and elevated divisions. Five hundred similar equipments, 300 of which are now in operation, have also been supplied to the New York Municipal Railway Corporation.

As indicated on the main circuit diagram, Fig. 4, the principal changes in main motor circuits, as well as the application and shutting off of power, and also the overload protection, are accomplished by means of seven independent electro-pneumatic switches of the HL type. In changing from series to parallel the usual bridging type of transition is utilized. The minor changes in the motor circuit connections required to accelerate the car are accomplished by means of a drum - type commutating switch, which is operated by differential air cylinders, and advanced progressively by the unbalanced pressure method. The contacts on this drum are protected by the unit switches from all arcing duty, and are so distributed as to carry the current of a single motor only. They effect the short-circuiting of resistance and also complete the circuits for the field control.

The six unit switches, together with the com-

mutating switch, and a drum-type reverser, also electropneumatically operated, are mounted in a single box and completely interconnected. However, the mounting is such that each piece of apparatus is isolated in gasproof compartments, and is in effect separately installed. A separately mounted line switch, especially designed for heavy duty, affords full overload protection, as well as serving to open the circuit under normal conditions. A special feature of this line switch is its ability to open quickly under sudden drops in line voltage, such as are sometimes caused on third-rail distribution system by momentary short-circuits, and thus protect the equipment against high surges in voltages which usually follows immediately after the disturbance. The circuit-breaking contacts are provided with an arc chute, venting to atmosphere. The line switch box also includes the overload trip relay, the line switch operating relay and an auxiliary relay, which lights the emergency battery lamps in the car when line power fails.

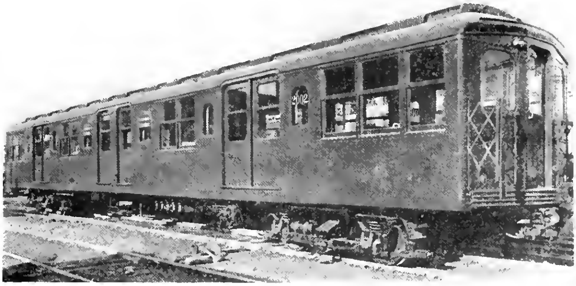


FIG. 2—CAR OF THE NEW YORK MUNICIPAL RAILWAY

The limit switch for governing the rate of automatic acceleration is mounted with the reverser in the control box. A separate compartment for the main wiring connections in the top of the control box also includes a main circuit terminal board, which acts as a distributing box for the entire equipment. A special design of grid resistor has been adopted whereby the weight of the set has been reduced approximately 40 percent without loss in continuous capacity.

While the reduction of weight has been an important consideration in the design of all of the apparatus, this feature has been most fully realized in the use of the drum-type commutating switch, which performs functions ordinarily requiring seven additional unit switches. A saving of 200 pounds is effected by this means alone. By combining all main circuit apparatus in a single box the work of installation is simplified, and the amount of cable reduced. Another direct result of the application of this type of control is the extreme simplicity of control circuits and the reduction in number of moving and wearing parts. The drum-type switch is entirely free from arcing, and the contact wear is therefore slight, while the simple nature of the parts makes for easy and reliable repairs.

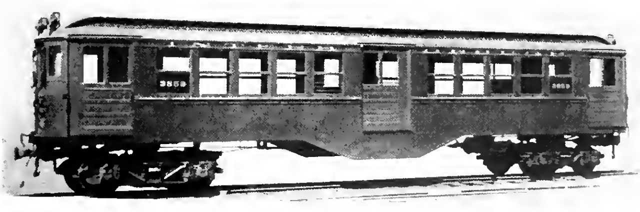


FIG. 3—CAR OF THE INTERBOROUGH RAPID TRANSIT COMPANY

The complete control equipment for two 170 hp motors consist of the following apparatus:—

	Approx. weight
1 Knife switch in box	50 lbs.
1 Fuse box	30 lbs.
1 Quick-acting line switch	230 lbs.
1 Control box	870 lbs.
1 Set of grid resistors	385 lbs.
2 Master controllers	90 lbs.
2 Control switches	10 lbs.
3 Control junc. boxes	70 lbs.
1 Main circuit junction box	23 lbs.
1 Set pneumatic details, including reservoir and air fittings	40 lbs.
1 Set insulating details for mounting apparatus	15 lbs.
1 Set of main and control cable	300 lbs.

Control power is derived from a 32 volt storage battery, charged in series with the compressor. The control supply is fed to the master controller at each end of the car. Adjacent to the controller are located control circuit switches, a reset switch for the circuit breaker, and other auxiliary circuits. The controller is provided with two handles, an accelerating and a reverse handle, the latter being removable in the "off" position. Movement of the reverse handle to an operating position energizes certain auxiliary circuits and, in addition, sets up the necessary circuits for securing emergency operation of the brakes in case the main handle is accidentally released while in an operating position. In addition to the seven wires necessary for the control proper, there are in the train line extra circuits for the electropneumatic brake system, the signal system, the governor synchronizing wire, and other auxiliaries.

Reference to the wiring diagram shows the following functions for the seven control wires:—No. 2, series; No. 1, progression; No. 3, parallel; No. 4, forward; No. 5, reverse; No. 6, circuit breaker reset; No. 0, common battery return.

There are three operating positions of the master controller;—switching, full series, and full parallel. The automatic control registers six notches in series, and four notches in parallel, including the high-speed, short-field notch.

The progression of the motor circuit apparatus is governed through the control circuits by the action of the limit switch, as it lifts and drops under the influence of motor current. The line switch opens the control circuit and drops out the switches on each car locally in case of failure of line voltage. This enables a train of any length to pass over gaps in the third rail without surging, since each car is cut off as it reaches the gap, and feeds up automatically as soon as power is restored. The line switch operates from line voltage, and is made sensitive to sudden drops in voltage by inserting additional resistance in the magnet circuit after the line switch has closed.

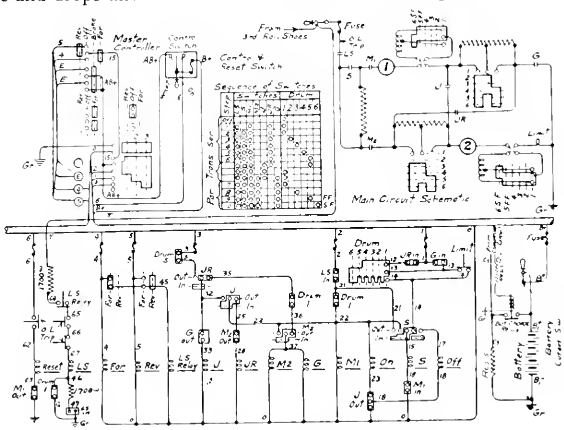


FIG. 4—MAIN CIRCUIT DIAGRAM OF SUBWAY CONTROL EQUIPMENT

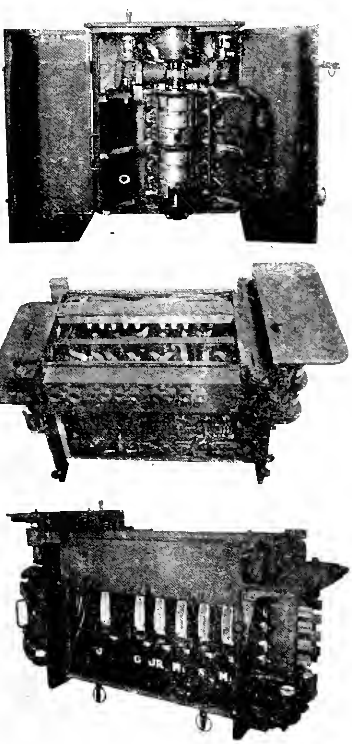


FIG. 5—UNIT SWITCH CONTROL BOX
Drum-type reverser at top.

The cylinders of the commutating switch are controlled by the *on* and *off* magnets, and the progression is secured through the closing and opening of the limit switch contacts in the *off* magnet circuit. This intermittently exhausts and charges the *off* cylinder, and allows the pressure in the *on* cylinder to advance the drum notch by notch.

It has been possible with comparatively few interlocks and a simple system of wiring to comply with all the fundamental laws of automatic control. In summarizing the effectiveness of this type of control the fundamental features may be stated briefly as follows:—

1—The power circuits can be closed only after the reverser is thrown to its proper position.

2—The control circuits for all switches open simultaneously when shutting off power.

3—The line voltage function prevents the control from progressing when power is partially or completely interrupted at gaps in the third rail, or on account of sleet.

4—All switches are dependent on the closing of the line switch, and must close in a predetermined sequence.

5—The progression circuit is established only after all other switches are properly closed and power has been applied.

6—Series switches are fully interlocked against parallel switches.

7—At least two wires must be energized at all times to hold power on the motors.

8—Three operating speeds are available. The progression may be held up at any desired intermediate speed by moving the controller back to the first position.

9—After having opened for any cause, the line switch cannot close until all control apparatus has assumed the initial position and the power supply is restored.

FIG. 6—MASTER CONTROLLER

In making the selection of a type of control which would embody the features described, due consideration was given to the service results secured with a variety of equipments through a period of several years. The standards now adopted will undoubtedly be perpetuated as long as the methods of rapid transit do not undergo radical changes.

Recent Installation Using Regenerative Control

LAKE ERIE & NORTHERN LOCOMOTIVE

C. C. Whittaker

AFTER extensive tests there was placed in service on the Lake Erie & Northern Railroad in April of this year a 1500 volt, direct-current regenerative locomotive. This locomotive, Fig. 1, is of the standard Baldwin-Westinghouse swivel-truck type, weighing 60 tons, having 36 inch wheels and is equipped with four standard 125 horse-power field-control motors, geared 24 : 53. It is designed for passenger or fast freight service and is capable of exerting a continuous tractive effort of 6520 lbs. at 26.5 miles per hour, and 8520 lbs. at 22 miles per hour.

The control for acceleration consists of the usual bridging control, except that the motors are bridged both in going from series to parallel, and from parallel to series when shutting off. Beside being necessary to the regenerative control, this feature is advantageous for acceleration alone, as much of the burning on the transition switches is eliminated.

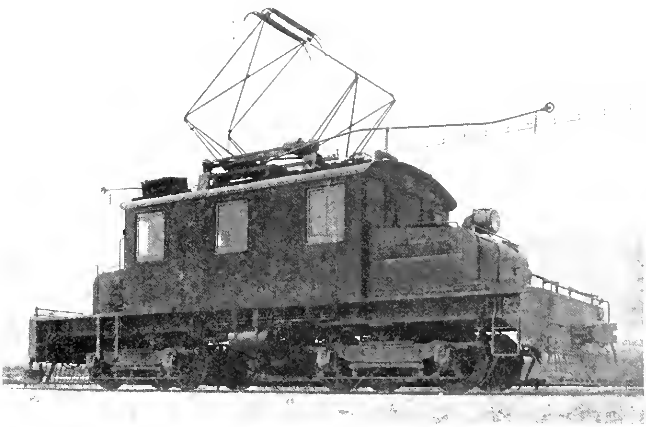


FIG. 1—LAKE ERIE & NORTHERN RAILROAD REGENERATIVE CONTROL LOCOMOTIVE

Both acceleration and regeneration are controlled by a single master controller. Fig. 2 shows the controller mounted in the locomotive cab. It is provided with the usual mechanical interlocks between the main and reverser levers and with other special mechanical interlocks which render false manipulation by the operator impossible. There are 16 notches for acceleration and 11 for regeneration. The operation of the control during acceleration is entirely manual, while during regeneration it is either manual or automatic, as desired.

Regeneration is accomplished by using the main motors as generators connected in series-parallel at the higher speeds, and all in series on the lower speeds. The fields are separately excited during regeneration by current from a motor-driven series generator, whose voltage ranges from 70 to 85 volts.

The field control feature is used only on acceleration, all regenerative running being done with the full field connection in order to decrease the current required for excitation. A simplified diagram of the connections obtained on the first notch when regenerating is shown in Fig. 3. From the location of the ground connection it will be seen that the regenerated current flowing from the substation through the ground connection passes through the same resistor as the exciting current from the generator, and in the same direction. The effect of this condition is to weaken the main motor fields automatically whenever the regenerated current increases. This means of securing motor stability has proven exceptionally effective, the motors never having flashed over either while on test or since installation.

By means of this inherent stability during regeneration, it is not essential that the line voltage be the same as the regenerated voltage when the locomotive motors are first connected to the line. Tests show that motors may be connected to the line without injury when regenerating at double line voltage. A selective relay is arranged to control the line switch connecting the motors to the line and is adjusted to cause this line switch to close whenever the controller is in a regenerative position and when the voltage generated by the motors is approximately 1500. If the speed of the locomotive is sufficiently high when the controller is turned to the braking position, the selective relay will act on the first notch; if not, the field drum will automatically rotate notch by notch, short-circuiting the resistance in series with the motor fields and thereby strengthening them until the voltage generated is sufficient to cause the selective relay to act, which will bring in the line switch and complete the main circuit to the line. The resistances *R* and *RR* in Fig. 3 are in series with the motors when the switch first closes, and the rotation of the field drum is stopped from the time the line switch closes until this series resistance has been cut out.

The field drum and change-over switch are shown in Fig. 4 mounted in the cab. The main drum is rotated

by means of a standard PK operating head. The upper part of the main drum is provided with interlock fingers so connected that it is possible to move the drum from the master controller, notch by notch, in either direction. The drum to the right manipulates the main and control

FIG. 2—INTERIOR OF LOCOMOTIVE
Showing controller and brake equipment at motorman's station.

change-over connections, and is operated by the usual reversing mechanism of the PK head. It also is controlled from the master controller.

Connected in series with the main motor armatures is a low-current relay, the function of which is to disconnect the motors from the line when regenerating with the motor fields at maximum excitation as soon as the regenerated current has fallen to approximately 30 amperes per motor. This feature prevents needless overheating of the main fields while the regenerated current is inappreciable.

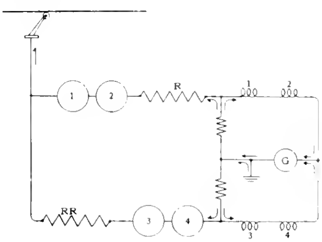


FIG. 3—SCHEMATIC DIAGRAM OF CONNECTIONS
When controller is on first notch for regeneration.

A fan, supplying air to the main motors and serving as a load to keep down the speed of the motor-generator set when there is no load on the generator, is mounted on an extension of the shaft at the generator end. The motor-generator set weighs 1500 lbs., or 50 percent more than the blower motor which would be required if this set were not used. The motor is provided with a series field connected in series with the field of the generator.

An oscillogram, taken during a complete automatic regenerative cycle, is shown in Fig. 5. At *A* the change over switch is operated by the controller and approximately 0.3 of a second afterward the selective relay acts. At *B* the main resistor switches close, after which the field drum increases the field excitation as the locomotive speed decreases. As the speed continues to decrease the motors are automatically connected in series at *C* without loss of torque and without the aid of airbrakes. This whole operation requires approximately 0.35 seconds. At *D* the main resistor switches are again closed, after which the motor fields are strengthened as the locomotive speed decreases. At *E* the locomotive is

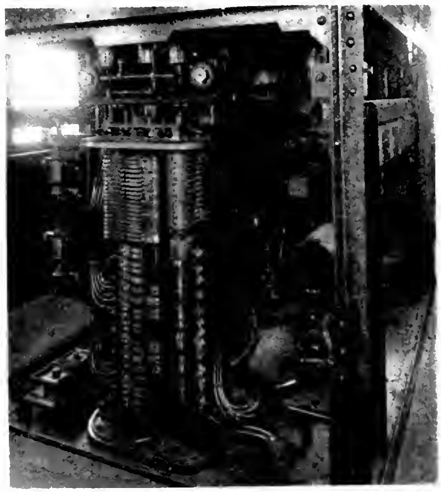


FIG. 4—FIELD DRUM AND CHANGE-OVER SWITCH
Mounted in locomotive.

coasting, and to the right of *E* is drawing current from the line and motoring at balanced speed with separately-excited motors. The low-current relay was not installed at the time this oscillogram was taken.

This locomotive is not designed to regenerate at speeds below seven miles per hour, since to do this would require too much current through the main fields. Moreover, in reducing the speed to seven miles per hour, approximately 93 percent of the kinetic energy which was stored in the train when running at 26.5 miles per hour has been utilized.

The smoothest stop is made when the controller lever is turned to the last notch, resulting in automatic regeneration. Then, as the ammeter indicates that the regenerated current is falling off after the last notch on the field drum has been reached, an airbrake application should be made which will begin to retard the train just

before the retardation from the regenerative brake ceases. When the regenerated current drops to 30 amperes the low-current relay will operate, disconnecting the motors from the line, and the remainder of the stop is made by the airbrakes.

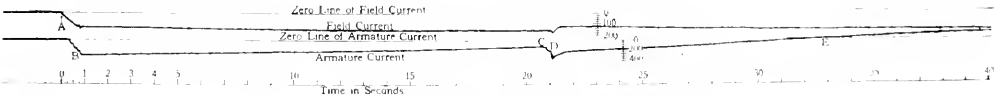


FIG. 5—OSCILLOGRAM OF LOCOMOTIVE REGENERATION
From an initial speed of 25 miles per hour without load.

Among the principal advantages which regenerative control in general offers are:—

1—Decrease in net power consumption.

2—Decrease in wear on brake shoes, wheels and brake rigging.

3—Decrease in brake shoe dust nuisance with reference to subways.

4—Decrease in heat liberated from brake shoes with reference to subways.

5—Additional means of braking, thereby affording greater safety.

From the results thus far obtained, when applied where conditions warrant this system of regenerative braking promises to yield more economical results than have previously been attained by any single achievement relative to electric railway equipment.

Pneumatically-Operated Devices on Locomotives and Cars

F. M. Nellis
Special Representative,
Westinghouse Airbrake Company

WITH the advent of the airbrake on railway trains, the use of compressed air to operate various devices in addition to the airbrake system has been found convenient and useful. A brief resume of these operations will doubtless prove interesting to those who have not kept in close contact with the rapidly increasing applications in railway service.

ELECTROPNEUMATIC CONTROLLERS

Compressed air controlled by electrically-operated valves is peculiarly well adapted for opening and closing the switches controlling circuits in electric railway service, either on cars or locomotives. The great pressure immediately available at the switch jaws insures heavy current-carrying capacity of the switch and minimum arcing and burning of the contacts.

Various combinations of circuits on electric cars and locomotives are made by a drum, which is caused to rotate by means of air cylinders. This means is often used for reversing the main motors, for changing the connections to accommodate a change in the trolley voltage, and for throwing pole changing or cascading switches.

Compressed air is also adapted by means of differential air cylinders to control the height of electrolyte in the liquid rheostat on large split-phase electric locomotives. Differential air cylinders actuated by a master controller are also used to rotate a drum controlling the main motor circuits on electric cars. On electric locomotives of large capacity compressed air is occasionally used for operating the main circuit breaker, thus permitting control from a distance. On all electric locomotives or cars the whistle is sounded by compressed air.

The pantograph trolley of electric locomotives is usually lowered by air pressure. Likewise, the contact shoe engaging with the third rail from which the current is taken is raised and lowered by air pressure, and controlled by the engineer in the cab. The multiple-unit arrangement of notching up the controller on electric locomotives and multiple-unit motor cars is generally performed by air pressure, automatically admitted into and discharged from a cylinder operated by magnet control valves.

On electric locomotives required to heat trains which are equipped with steam-heating pipes a small flash boiler is employed. The fuel for this boiler is kerosene oil, atomized while getting up steam by compressed air taken from the airbrake system.

CARS

On steam road passenger cars, also electric railway cars running in trains (and in some cases on single motor cars), an air whistle signal is so designed and connected that when the conductor or one of the train crew pulls the cord in any car of the train a signal blast will sound from the whistle in the motorman's cab. These blasts may be arranged to convey to the engineer or the motorman any predetermined signal. Necessary pressure is admitted into the signaling system through a suitable reducing valve from the main reservoir on the engine.

One system of passenger car lighting takes air pressure from the auxiliary reservoir of the brake system, through a governor and non-return check valve, to a carburetor, where it is mixed with gasoline supplied by a storage tank. The air and gasoline are formed into

an illuminating gas, which is piped up into the burners inside the car.

On sleeping cars, parlor cars and dining cars of steam railroads, air pressure is used to force water from a large supply tank under the car up into the basins and toilet of the washrooms and to the kitchen of the dining car.

On freight cars, such as are used in work trains, air pressure is frequently used to operate a crane, or hoist, to lift rails and other track material from cars to the ground at the side of the track where they are deposited; also certain types of dump cars are unloaded by air pressure by pneumatically opening the drop side doors or drop bottom doors depositing the load of ballast or dirt on the track or at its sides. The air pressure for this work is taken from the brake pipe at a time when the train is standing still, and is passed into an independent storage reservoir, whence the working supply is taken as required. A pressure governor and non-return check valve are suitably arranged between the brake pipe and pressure tank to prevent air from passing from the brake pipe to the storage reservoir at undue times, also to prevent the return of air from the pressure tank back into the brake pipe.

LOCOMOTIVES

On locomotives, both passenger and freight, the uses for compressed air to operate devices are more numerous. The bell ringer takes its supply from a suitable main reservoir connection into a cylinder, to which it is admitted automatically by the movement of the bell when ringing. The engineer or fireman starts the bell ringing, or stops it, with a small air valve in the cab which connects by pipe to the bell-ringer apparatus.

The modern, heavy locomotive requires such heavy valve gear parts as to make it exceedingly difficult, or even impossible, for the engineer to manually reverse his engine or to notch up the lever in the quadrant while steam is being used. A pneumatically-operated reversing gear is therefore installed on many of these locomotives, being worked by a simple valve in the cab by the engineer, and thus relieving him of the exceedingly heavy work required to handle the reverse lever.

A pneumatically-operated fire door is frequently employed on heavy steam locomotives. Air pressure admitted and released from a special cylinder arrangement opens and closes the fire door, as desired by the fireman, and is operated by the fireman from a treadle on the foot-board. This arrangement not only relieves the fireman of the burden of opening and closing the fire door with each shovelful of coal placed, but effects a considerable saving of fuel, and also prevents damage done by cold air rushing against the fire box sheets and tube sheets.

On railroads where locomotives are supplied with water from long, shallow tanks in the middle of the track while running, instead of stopping the train at elevated tanks by the side of the track, a scoop is dropped into the track tank and water thereby scooped up from the track trough into the tank at a fairly high rate of speed. Some few roads still employ hand levers for lowering and raising the scoop, but the large majority of roads use air pressure, admitted and exhausted by a simple valve in the cab, similar to the bell ringer and reversing mechanisms.

On some compound locomotives an intercepting valve is provided, by which, when the engine starts, high-pressure steam may be temporarily used in the low-pressure cylinders until a certain rate of headway is obtained, say 10 or 15 miles per hour, when the intercepting valve reverses by pneumatic pressure and automatically throws the engine into compound. A manually-operated air valve is also sometimes used, by which this intercepting valve may be operated by the engineer.

On some roads in the West where water is bad and frequent blowing off of the water is necessary to stop priming of the boiler when the train is running, a pneumatic blow-off cock is operated from a simple valve in the cab.

The pneumatic sander has become a necessary device generally on all locomotives, as it will more evenly and more accurately supply the necessary amount of sand on the rail to keep the driving wheels from slipping in bad weather. The sand is forcibly blown from the sand pipes immediately under the wheels and on the rail, thus preventing a side wind from clearing the sand from the top of the rail as fast as it falls, which was one of the faults with the old hand-operated, gravity system.

Cylinder cocks on some locomotives are pneumatically operated. Likewise, ash pans are pneumatically dumped, thus making it unnecessary for the fireman to get under the engine while on the road to clean out an ash pan which has filled up.

These are the general uses to which compressed air, taken from the airbrake system, is used in steam and electric service. The air compressor on steam roads must necessarily be of greater capacity to supply pressure for these devices apart from supplying pressure to the airbrake system. This is usually taken care of by installing one or more cross-compound compressors on the locomotive, or two simple compressors, placed side by side.

In each of these cases the required air pressure is taken from the airbrake system at some point connected to the auxiliary reservoir, and never from the brake pipe direct. The reason for this is that should a supply of air pressure be taken from the brake pipe when the train was running, that supply would make a reduction in brake pipe pressure similar to an amount taken by the engineer with his brake valve, or by the trainman with the conductor's valve, and the result would be an undesired brake application. The earlier forms of these systems drew directly from the brake pipe, and the undesired application invariably followed an operation of the device. Precaution should also be taken to prevent the return of air pressure into the brake pipe after it has been passed into the storage reservoir, as a return would increase the brake pipe pressure, thus releasing the brakes.

The Relation of Stokers to Smoke Abatement*

Joseph G. Worker
Manager, Stoker Section,
Westinghouse Electric & Mfg. Company

FEDERAL investigations disclosed a few years ago that out of 240 cities having less than 50 000 inhabitants only twelve reported either a smoke ordinance or an official charged with smoke abatement; out of sixty cities of 50 000 to 200 000 inhabitants only seventeen were making a more or less vigorous effort to suppress the nuisance and, out of these, six were the most active; while out of twenty-eight cities having a population of 200 000 of over, five were practically making no effort toward smoke abatement. If the above conditions exist today, it surely must be due to a lack of support of the people. Whatever matured public opinion wants in smoke abatement it can now have.

Nearly all power used in the United States is obtained by the burning of soft coal. The production of the anthracite fields is practically all taken for domestic use, and it is evident that this country must depend on its bituminous coals for manufacturing purposes.

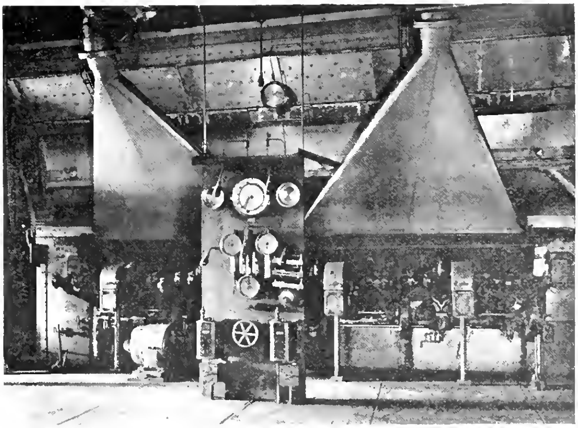


FIG. 1—INSTALLATION OF WESTINGHOUSE UNDERFEED STOKERS
Delray Power House, Detroit Edison Company.

CAUSES OF SMOKE

Smoke is produced for the reason that coal is not burned properly, and the reason it is not burned properly under steam boilers may be due to a number of things:—

1—The boiler room may be too hot, dirty and unattractive a place for managers to go and investigate and correct bad conditions.

2—Instruments may not be installed to indicate when the fuel is being burned properly; or if instruments are installed they may be clogged up with coal soot and inoperative; or the fireman may have little intelligent knowledge of the use of the instruments.

3—The grate, or stoker, may be too large or too small, or not properly designed for the fuel that is used.

4—There may not be sufficient draft for the amount of coal that must be burned on the grate; the stack may be too small, or too large; or the flues improperly designed.

5—The boiler-room attendants may not be trained men, and for this reason the equipment may be improperly operated.

6—The furnace may be designed improperly; there may be insufficient combustion space; the furnace standards that are known to be right may have been slighted.

7—Refuse may be mixed with the coal or thrown onto the grate, and an effort made to burn it.

8—The load may be very fluctuating or changed quickly, without warning to the boiler-room attendants.

9—Excessive overloads may have to be maintained for short periods.

10—After the equipment is installed the operating conditions may have changed; the equipment then being unsuited for the changed conditions.

11—The equipment may be misused and not kept in proper operative condition.

12—The boiler setting may be leaky and in bad condition.

13—The coal-burning equipment may be out of date.

These causes of smoke may seem trivial, but they must be considered in the question of smoke abatement. The smoke-abatement movement must be projected upon lines that are exact, and its most distinguishing feature will be the balancing of responsibility between the people and the violators. All of us appreciate that the ideal cannot be completely realized, but nothing should be placed in the way to hinder a near approach to this realization.

The large central stations are rapidly securing a complete smoke abatement. They are going through elaborate processes to determine the most economical and smokeless stoker and boiler combination, and are building adequate stacks to provide sufficient draft for the maximum overload requirements. On account of the typical power station load curve and the desirability of carrying the peak by merely raising the rate of steaming of the boilers in service, old equipment is being replaced by the most up-to-date high-capacity equipment. The boiler-room operators are being trained and the stokers and boilers are being operated along scientific lines. This requires the use of suitable instruments, such as those shown in Fig. 2. These instruments indicate to the operators just how the coal is being burned. There are steam pressure gauges, steam flow meters, draft

*From a paper before the Smoke Prevention Association, at St. Louis, Mo., Sept. 28, 1916.

gauges, CO_2 recorders, flue-temperature recorders, and controlling devices for motor-operated dampers. Throttle extensions from the turbine-driven blowers are close at hand for regulating the air, and motor control close at hand for regulating the coal feed.

It is quite evident, therefore, that progress has been made in the utilization of the coal under steam boilers. Specifications for stokers nowadays read as follows:—

> "The load of the station fluctuates widely over different portions of the day. It is also subject to rapid change, to special operating conditions, as sudden showers, etc. The stoker shall be capable of meeting these conditions within the specified capacity of 300 percent of rating and provide for the manipulations of the fires in an efficient manner and *within the limits set by the smoke ordinance.*"

From this it is evident wherein the question of smoke abatement bears relation to the development of mechanical stokers for burning of bituminous coals. The ability to meet such specifications has, as a conse-

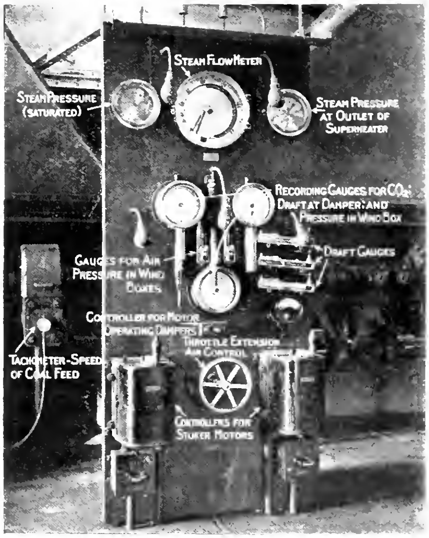


FIG. 2—GAUGE BOARD FOR OPERATING UNDERFEED STOKERS
Located immediately in front of the stokers

quence, been brought about by the improvement in mechanical stokers and furnace design.

DEVELOPMENT OF STOKERS

There have been very few changes in the mechanical design of the chain grate or overfeed type of stoker. Higher standards of settings have come into force which have eliminated, to a great extent, the smoke problems of this class of equipment.

There has, however, been a tendency to install these stokers under conditions which required a quick change in load, and where excessive overloads had to be maintained. It was under severe conditions of this kind that natural draft stokers produced smoke. It has been necessary, therefore, to develop an equipment that would not smoke even under these severe conditions, and this has led to the development of the underfeed stoker and forced draft. This development has not been entirely a problem of obtaining high steaming capacities, as most people suppose. If this were true, natural draft stokers could be installed with excessive grate surface and almost any desired capacity obtained. Even though the character of the boiler setting allowed the installation of more grate surface—if it were required that this

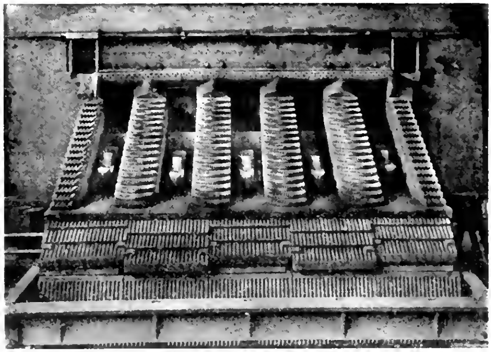


FIG. 3—UNDERFEED STOKERS
Showing series of inclined retorts and corrugated tuyeres

equipment be operated at normal rating—the efficiency would be very low, due to the fact that part of the grate surface would not be effective, and there would be no control over the air admission.

From a general survey of power plants it would seem that the present method of operation is around 150 percent of boiler rating. At this steaming capacity, the fires are handled very easily, and there is no trouble with clinkers, smoke, brick work or maintenance. The very best economy is also obtained at this steaming rate. The present-day requirements are to maintain this economy at normal steaming capacities, and also to provide

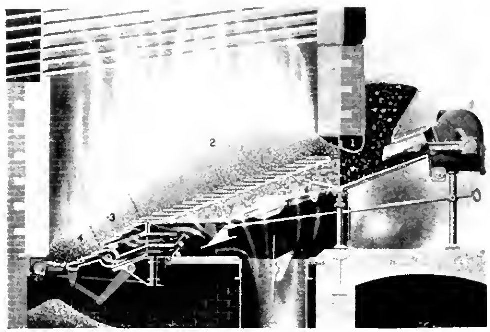


FIG. 4—SECTION OF FURNACE CHAMBER
Showing operating principle and air control of underfeed stoker.

reserve capacity in the same equipment so that sudden demands for steam can be met. The need is for flexibility of equipment to meet any kind of an emergency. If it is necessary to take a boiler off of the line, it is expected that the equipment already in service and

under fire will take up the load and handle it with sustained reliability.

Consider a case of a plant containing two 500 horsepower boilers, both being operated at about 125 percent of boiler rating. This, no doubt, in general cases is a very efficient rate, and high efficiency can be maintained. If one of these boilers is lost the equipment in service must be capable of delivering 1250 boiler horsepower, or a steaming capacity of 250 percent of boiler rating. Unless the stoking equipment is capable of doing this, a third boiler would be necessary for this reserve capacity and, in most cases, this boiler must be carried on "bank" so that this reserve capacity can be put on the line with the least possible delay.

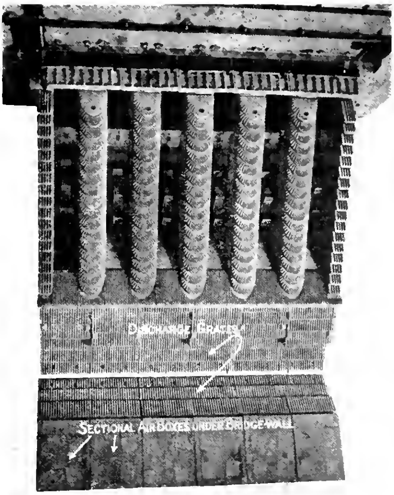


FIG. 5—PLAN VIEW OF UNDERFEED STOKER

Boiler-room economics, therefore, has demanded that this reserve capacity be placed in the coal-burning equipment and not in idle boilers.

This phase of the subject will probably be more apparent upon studying the condition of plants that are now replacing natural draft stoking equipment by forced draft underfeed equipment. This equipment is not being replaced because it does not handle the coal properly, or on account of inefficiency, but due to the fact that the rate of combustion is so close to the maximum capacity of equipment that there is no reserve capacity left. Obviously, there are only two things to do in cases of this kind,—either install additional boilers or a stoker equipment with a larger margin of reserve. The underfeed stoker, therefore, has been developed to give a high efficiency at normal ratings and a wide range of operation with enormous reserve capacity; and not primarily to give high steaming capacity.

THE INCLINED UNDERFEED STOKER

As shown by Figs. 3 and 4, the inclined underfeed stoker is made up of a series of inclined retorts, each retort consisting of a fuel trough and two parallel tuyere boxes. Fuel fed into the hopper drops in front of the cylindrical ram when the latter is in its outward position. On its inward stroke the ram pushes the coal ahead of it into the furnace and beneath that previously introduced. The slope of the grates is such that gravity does not materially affect the forward movement of the fuel. Secondary rams, driven from the main rams by lost motion connections, are therefore provided. The speed of the rams can be varied automatically to suit different load conditions, and the secondary rams can, through the lost motion connections, be adjusted so as to give that condition of fuel which best suits the coal used.

The fresh fuel under the action of the main rams is forced under the incandescent zone; the coked fuel is moved farther backward by the combined action of the main and secondary rams; and finally the ash itself is forced onto the discharge grates. The entire action of the stoker is to move the fuel necessary to carry any desired load uniformly backward and to dispose of the residue of clinker and ash. The discharge grates consist of two dump grates providing a large space for discharge of the refuse, Fig. 5, and are manually operated from the side of the furnace.

The shape of the fuel bed formed with an underfeed stoker is of considerable importance. Due to the relatively small incline (20 degrees) and the use of deflecting plates, the shape of the fuel bed can be varied for coals having different coking properties and different percentages of volatile matter.

Air Supply—The air supply to each portion of the furnace is under the control of the operator. From Fig. 4 it will be seen that air from a suitable fan or blower is admitted to the sealed furnace chamber through the main air duct, this supply being controlled by the butterfly valve. From this chamber the air goes:—1, to the air-distributing box located at the front of the furnace above the tuyeres; 2, through the tuyeres themselves to the fuel bed; 3, over the feed section, and 4, to the front discharge grate. The rear discharge grate is supplied with air from the main air duct.

The butterfly valve and air damper for the lower grates are operated by means of suitable levers from the front of the furnace. Dampers controlling the air to the overfeed and discharge grates are operated from the side of the furnace by levers.

FIG. 6—TOP VIEW OF TUYERES
Showing method of interlocking.

The shape of the fuel bed can be controlled by the operator and, in general, it should conform to that shown in Fig. 4, because it has been found that to burn a certain amount of coal per square foot of grate, a

definite air pressure, independent of the resistance due to the thickness of the fuel bed, is required. Most of the volatile gases are distilled and pass through the fuel bed at the front, and as these hydrocarbons require about three times as much air for combustion as does the coke, the importance of a large air supply at this point is apparent.

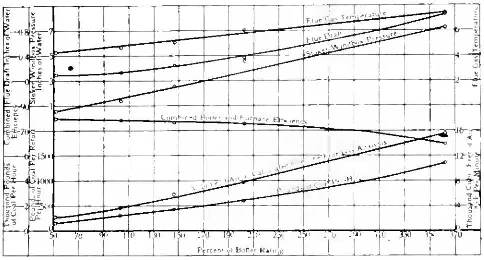


FIG. 7—PERFORMANCE CURVES FOR INCLINED UNDERFEED STOKER

Flue draft plotted as drop through boiler. Stoker windbox pressure plotted as drop through grate and fuel bed. Average coil analysis:—Moisture = 3.32; volatile matter = 23.32; fixed carbon = 67.02; ash = 6.42; sulphur = 1.742; b.t.u. (dry) = 14 932. Flue gas temperatures 100 times those indicated.

Air at the highest pressure employed for a certain rating enters directly under the front part of the stoker. Secondary air entering from the air-distributing box through a number of orifices extending across the entire width of the furnace mixes with the carbon-monoxide and gives a thorough mixture of gas and air over the fire. The proper volume of air at a lower pressure is admitted to the lower end of the fuel bed, this air being decreased in pressure and volume to suit the decreased thickness and combustible percentage of the fuel bed.

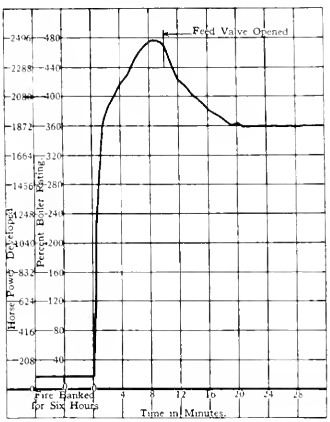


FIG. 8—CAPACITY CURVE

Grate Construction—Corrugated tuyeres and grates are used throughout. As shown by Fig. 3, the tuyeres, supported by a box girder, overlap each other, the entire series being held in position by the upper block, which is packed with asbestos to allow for expansion. The uniform thickness of the tuyeres and the method used to interlock them, preventing displacement from the tuyere boxes, are clearly shown in Fig. 6.

Driving Mechanism—The main rams and the secondary rams are operated from one crank shaft, as shown in Fig. 1. This shaft operates at a low speed of one-half revolution per minute when burning about 500 pounds of coal per retort, and is driven from a high-speed shaft by means of two sets of worm gears, the speed reduction being about 350 to 1. The gears are enclosed and operated in a bath of graphite and oil. A large hinged cover on the gear case makes inspection easy. The crank shaft and high-speed shaft are divided into interchangeable sections, each section driving two to four rams. By means of clutches on the high-speed shaft, any particular section may be stopped.

TABLE I—CHARACTERISTICS OF COLVER (W. VA.) SCREENINGS

Test No.	1	2	3	4	5
Moisture	4.	2.66	3.9	3.05	2.83
Volatile Matter	24.11	24.47	24.54	24.60	22.67
Fixed Carbon	68.61	68.80	68.57	69.19	71.52
Ash	7.28	6.73	6.89	6.21	5.81
Sulphur	1.25	1.57	1.88	1.95	2.07
B.T.U. as Fired	14.364	14.539	14.329	14.440	14.535
Duration of Test	24 Hrs.	24 Hrs.	13.25 Hrs.	24 Hrs.	2 Hrs.
Percent Boiler Rating	50.7	103.2	145.5	202.8	361.75
Combined Boiler and Furnace Efficiency	79.7	78.02	76.6	75.58	....

TABLE II—CHARACTERISTICS OF WESTERN COALS

Test No.	1	2	3	4	5
Moisture	14.49	15.9	16.3	15.28	16.0
Volatile Matter	41.91	36.3	36.1	36.17	36.8
Fixed Carbon	44.40	44.5	43.7	42.08	45.8
Ash	13.69	19.2	20.2	21.75	17.4
Sulphur	0.63	5.7	5.4	3.84	5.1
B.T.U. as Fired	10270	8953	8850	9070	9384
Duration of Test	22.5 Hr.	10 Hrs.	8 Hrs.	24 Hrs.	8 Hrs.
Percent Boiler Rating	206	208	153.2	149.6	236
Combined Boiler and Furnace Efficiency	73.6	73.9	74.2	76.3	68

Test No. 1—Wyoming screenings.

Tests Nos. 2, 3, 4 and 5—Illinois (Fulton County) screenings

The high-speed shaft is generally driven by means of sprockets and chains from a line shaft placed below the operating floor. The line shaft can be driven by a steam engine or an electric motor and is, in most cases, so controlled with respect to the fan drive that their speeds vary proportionally with each other. A protective device, consisting of a mild steel shearing pin, is used so no damage will occur should foreign substances be accidentally admitted with the coal and block the movement of the rams.

Capacity and Efficiency—The problem most prominent before engineers at the present time is to obtain high evaporative capacity with sustained efficiency and

smokeless operation. In this respect the application of the forced draft underfeed stoker has given most notable results. Calculated performance curves for an inclined underfeed stoker, Fig. 7, give practically all the important engineering data required for a given case:—

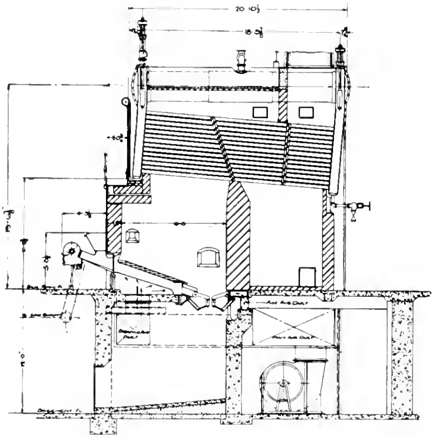


FIG. 9—APPLICATION OF UNDERFFED STOKERS TO THE EDGEMOOR TYPE OF BOILER

Boiler headers set ten feet from floor line.

The pounds of coal burned per hour, the volume of air required at different ratings, the efficiency at different ratings, the air pressure in the wind boxes, the flue draft and flue temperature. These characteristic curves vary

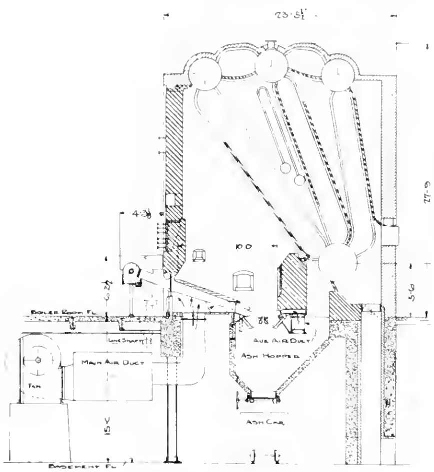


FIG. 10—APPLICATION OF UNDERFEED STOKER TO THE STIRLING TYPE OF BOILER

The furnace arch, which is generally used with natural draft stokers, is eliminated in order to obtain the full effect of the radiant heat from the fuel bed.

for different coal, boiler, draft, load and setting conditions.

The capacity and efficiency performance with West Virginia, Illinois and Wyoming coals is given in Tables I and II. The results so far obtained are sufficiently gratifying to warrant a more extensive development with coals that are more difficult to burn.

Flexibility—On account of the ease in the control of air and coal feed for particular conditions, the equip-

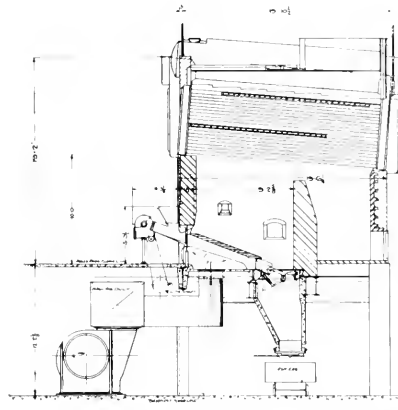


FIG. 11—APPLICATION OF UNDERFEED STOKER TO THE HEINE TYPE OF BOILER

The headers of the boilers are set ten feet from the floor line, thus providing a large combustion chamber.

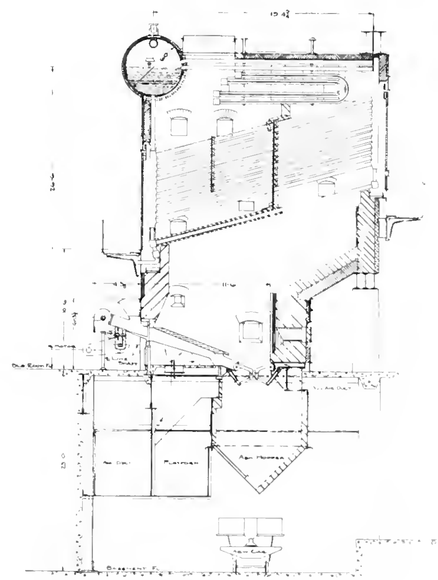


FIG. 12—APPLICATION OF UNDERFEED STOKER TO BABCOCK AND WILCOX BOILERS OF THE CROSS-DRUM TYPE

This combination is very effective as far as smokelessness is concerned. Boilers are generally of large capacity, 1200 to 1500 hp. Doors have been placed in the bridge wall for observation of the furnace from the rear.

ment is very flexible. A carefully conducted test, Fig. 8, made on a 520 horse-power boiler which had been banked for six hours, showed that after one minute 1700 horse-power was developed, and after two minutes,

1900 horse-power. After 8.75 minutes 2475 horse-power, or 475 percent of rating, was developed with one-inch flue draft and 4.1 inches air pressure. The feed valve was opened after ten minutes and the output gradually diminished to 1860 horse-power, which rating was maintained for half an hour, with the water level slowly rising. The feed-water temperature was 210 degrees F., and readings were taken at 15 second intervals from a steam flow meter previously tested and found correct as checked with boiler evaporation tests.

Maintenance—The tuyere blocks of the underfeed stoker are covered by a heavy layer of green fuel, and the air passing through them and the overfeed and discharge grates has a cooling effect, which protects them to the extent that the maintenance on the stoker is very low. For a stoker installed under an ordinary 500 horse-power boiler $85 per year should cover replacement of worn-out or burned-out stoker parts operated up to 300 percent of rating.

FIG. 13—INSTALLATION OF UNDERFEED STOKERS
Bluestone power house of the Norfolk & Western Railroad.

The maintenance of the brick work depends so much upon local conditions, the operation of the equipment, and the grade and workmanship of the masonry, that a statement of the average brick work maintenance of a furnace could not be made that would be applicable to general cases.

Steam Used by Auxiliaries—The steam utilized by the auxiliaries for driving stokers and forced draft fans varies according to the number and arrangement of these units. Steam-driven auxiliaries require from two to three percent of the amount of steam generated, but where the exhaust from these units is returned for feed water heating this heat loss is reduced to one-third of one percent. Where motor-driven auxiliaries are used the loss is about one percent. The effect of the auxiliaries, therefore, on the economy of the plant depends upon each case and cannot be generalized.

Application—The underfeed stoker is not one that can be applied successfully to all types of boilers without regard to the setting standards that are now established. Where heavy peak loads or sudden changes in loads must be met it is very important that sufficient combustion space be provided. When underfeed stokers are applied to horizontal return tubular boilers the boiler header should not be less than ten feet from the floor line.

There are installations of underfeed stokers going in today that are prejudicial to good furnace performance. The same thoughtful attention must be given to the application of underfeed stokers that are now given to the overfeed and chain grate installations. Figs. 9, 10, 11 and 12 show typical combination of the underfeed stoker to the different types of boilers.

THE SELECTION OF STOKER EQUIPMENT

General—No one type of stoker is best suited to all applications. Local conditions of load, coal, draft and boiler settings must be considered in selecting the type of stoker, and unless these engineering features are carefully analyzed, and a decision based on this analysis, an unsatisfactory installation is sure to result.

There are conditions under which the chain grate, overfeed or underfeed type of stoker is best suited, and the success or failure of an installation will depend largely upon how exact the engineering analysis is made. While each installation must be considered and analyzed individually, a few general principles may be given for each type of stoker.

Overfeed Type Stokers—The overfeed stoker is more nearly a universal stoker than any other type. It burns very satisfactorily the high volatile coals found in Indiana and Illinois, and also the high fixed carbon coals, such as are largely used in the East. It is unsuitable for lignite fuels. The stoker is very accessible, no vital parts which may become damaged being out of sight. Ashes can be removed on the boiler-room floor, so that expensive basements or ash pits are not necessary. Where maximum capacity is not over 200 percent of boiler rating, and with proper draft and furnace design, this type of stoker will give very satisfactory results. This stoker is particularly adapted to return tubular boiler applications and to boilers generally found in the moderate-size boiler plants.

Chain Grate Stokers—The field for chain grate stokers is limited to the high volatile coals found in Indiana and Illinois and parts of the West; it also handles the lignite fuels of the West with a lesser degree of satisfaction. It has not been adapted to burning the low volatile coals, such as are used in the East. For the installation of this type of stoker the boiler room should be arranged so that the stoker can be rolled out in front of the boilers for repairs without interfering with the work of the boiler-room attendants. The application of this stoker should provide a pit for collecting the droppage of fine coal through the grate and suitable pits for collecting the ash and refuse. It does not work very satisfactorily to take the ashes out on the boiler-room floor, and the most satisfactory plants have a basement where the ashes are removed below. This stoker gives excellent results for uniform loads. Under

proper draft and setting conditions this stoker is smokeless, easy to operate and efficient, but should not be used for applications that require much over 200 percent of boiler rating for maximum capacity.

Underfeed Stokers—The field for underfeed stokers is in plants that have large peak loads or where sudden increases in steam demands must be met. Where maximum reserve capacities of 300 or even 400 percent of boiler rating is required this type of stoker should be used. The stoker should then be surrounded with the proper setting conditions. There should be ample combustion space, large pits for collecting ash and refuse, and either a tunnel or underground construction for air ducts. As forced draft is required for this stoker, the first cost per rated horse-power is high, but in plants subject to conditions which make the application of this stoker desirable it will be found, in most cases, that the additional expense is justified. The number of boiler units may be reduced by its use and a saving in the cost of the complete boiler plant effected.

600-1200 and 750-1500 Volt Direct-Current Change-Over Switches

H. R. Meyer

On high-speed interurban electric railways which employ voltages above the usual standard for city service, and where cars run also on city or low-voltage sections, it becomes necessary under certain conditions to make changes in the arrangement of the main motor and compressor wiring, as well as in the lighting and control circuits, in order to secure satisfactory operation on the higher as well as the lower voltages. To make the necessary changes in all circuits when changing from a low-voltage zone to another zone of different potential some form of change-over switch must be employed. These change-over switches are usually made in the form of a combination of contacts and fingers, with the contacts placed on a movable drum, so that two or more combinations can be obtained by a movement of the drum. Except in a very few cases, the value of the higher voltage is twice that of the lower voltage, and this arrangement permits a change-over of connections of the simplest form.

FIG. 1—ELECTROPNEUMATICALLY-OPERATED DYNAMOTOR CHANGE-OVER SWITCH

In making a general survey of high-voltage, direct-current interurban lines, there are three distinct systems which present themselves for the consideration of the investigator, which may be classified in the sequence of desirability from an engineering viewpoint as follows:—

System 1—Straight 1200 or 1500 volt operation.
System 2—600/1200 or 750/1500 volt operation with half speed of the motors on the lower voltage.
System 3—600/1200 or 750/1500 volt operation with full speed of the motors on the lower voltage.

System 1 covers that portion of the railway field where strictly interurban service is contemplated. In other words, when a road is to be run between and through towns where no low-voltage railways exist, or where the terminals of the high-voltage road are to remain at the outskirts of the larger city in which low-voltage railways are in operation and where the higher voltages are not permitted, a straight 1200 or 1500 volt system is usually installed. As no change in speed due to a radical change in voltage is encountered with this system, the connections for the main circuits are arranged as shown in Fig. 2.

System 2 includes those roads where a small amount of low-voltage city running is necessary and where fast schedules and close headway are not considered necessary. No change of main circuits is required in this case, and the connections would be the same as in *System 1* were it not for the necessity of changes in the auxiliary circuits in order to obtain full voltage on the lamps and control system during low-voltage operation. Connections for this system are shown in Fig. 3.

System 3—Wherever low-voltage running is encountered in connection with high-voltage interurban service, and where close schedules and headway must be maintained, *System 3* is employed. In order to obtain the same speed in the low-voltage as is obtained in the high-voltage zone the circuits are arranged as shown in Fig. 4.

When a change-over of part of a low-voltage, direct-current railway system to a higher voltage, or the building of a high-voltage, direct-current line where cars must operate over a section of a low-voltage line is contemplated, one of the first questions of importance which confronts the engineer in charge is the effect that the change in speed due to changes in voltage will have on his schedules.

Except in a very few cases, where an interurban high-voltage extension to an existing low-voltage city system is made, the high-voltage section is twice the voltage of the low-voltage section, so that either half or full speed can be obtained on the low-voltage section by

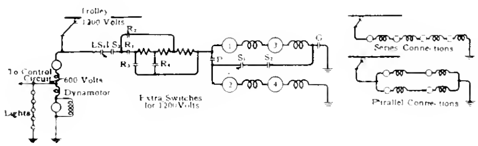


FIG. 2—SCHEMATIC DIAGRAM FOR 1200 VOLT EQUIPMENT WITH HL CONTROL

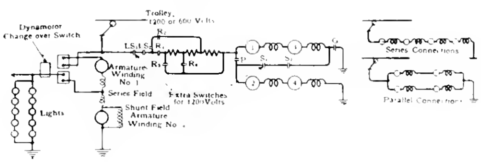


FIG. 3—SCHEMATIC DIAGRAM FOR 600-1200 VOLT EQUIPMENT
With HL control arranged for half-speed operation on 600 volts.

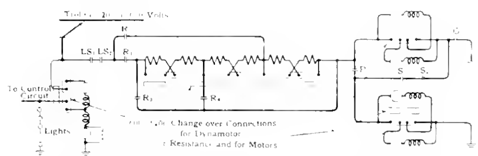


FIG. 4—SCHEMATIC DIAGRAM FOR 600-1200 VOLT EQUIPMENT
With HL control arranged for full-speed operation on 600 volts.

means of a few simple changes in connections. When there is only a small amount of moderate speed city running, it is not necessary to operate the motors at full speed on the low-voltage section.

By operating at half speed on the low-voltage section the necessity of a main circuit change-over device for rearranging the main circuits is obviated. However, it is essential that the control circuits obtain full voltage on both the low and high-voltage sections, and it is almost universally required that the lights burn at full brilliancy at all times. To obtain the correct arrangement of circuits on both voltages where a dynamotor is used in connection with the compressor or alone, a change-over switch is used as shown in Fig. 1, with connections as in Fig. 5. This type of change-over switch is operated electropneumatically from the operating platform and is satisfactory for use where cars are operated in trains, since the switches on all cars can be operated at the same time. This change-over switch can also be arranged for use on equipments which employ a double-commutator compressor, which is sometimes necessary to obtain full speed of the compressor on the lower voltage, where half speed does not give the required air pressure. In a number of cases it has been found unnecessary to run the compressor at full speed, but where such a condition exists a minimum amount of air is used. In the construction of this change-over switch an air cylinder is used with an operating magnet similar to that employed in HL control. The piston rod of this cylinder assembly is directly connected to a set of contacts and indirectly to a set of fingers which, when in the normal or high-voltage position, connect both sections of the dynamotor in series, and when in the low-voltage position connect both sections in parallel.

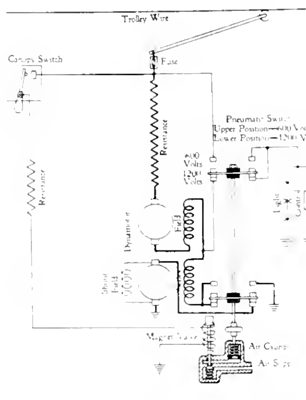


FIG. 5—DIAGRAM OF CONNECTIONS OF SWITCH SHOWN IN FIG. 1

In the normal or high-voltage position the change-over switch is in the out position and the operating magnet is not energized. When running onto the low-voltage section of the line the operating magnet is energized by means of a control switch located in the motorman's cab. When this coil is energized, air is admitted to the cylinder and the change-over switch is thrown to the in or low-voltage position.

In connection with equipments that may run at only half speed on the low-voltage section, and where no dynamotor is used to furnish power for the control and lights, a change-over switch is necessary to connect the lighting circuits in series or in parallel, depending on the voltage, and to take care of certain control circuits where it is imperative that the operating voltage remain practically constant. A hand-operated change-over switch which is used very frequently for this type of service is shown in Fig. 6. The method of changing connections is shown in Fig. 3. For single-car, single-end operation this change-over switch is mounted in the cab within reach of the operator.

When it becomes necessary, on half-speed equipment, to operate cars in trains, and it is undesirable to operate the change-over switches on each car separately, a change-over switch of the type shown in Fig. 7 is sometimes used. This switch takes care of the double-commutator compressor and heater circuits, as well as lights and control.

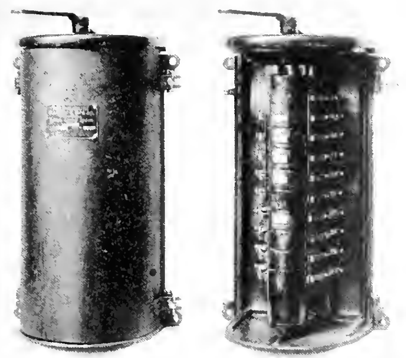


FIG. 6—HAND-OPERATED CHANGE-OVER SWITCH
For the control and lighting circuits, providing for half speed on 600 volts.

For equipments requiring full-speed operation on the low-voltage sections a change-over switch similar to the one shown in Fig. 8 is generally used, although in some cases these switches are operated electropneumatically or by air alone. The latter condition is usually found on express cars intended for single-car operation. The type of change-over switch illustrated in Fig. 8 is arranged to take care of the main motor circuit, compressor, dynamotor control, lighting and all auxiliary circuit which require a change in connections when changing from the low to the high-voltage sections, or vice versa.

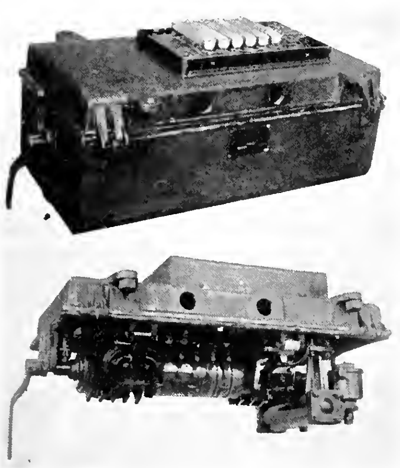


FIG. 7—CHANGE-OVER SWITCH FOR TRAIN OPERATION

When changing from the high-voltage to the low-voltage position the starting resistance sections are paralleled to give one-quarter the resistance, and the motors are connected in parallel, as shown in Fig. 4. As the voltage has been reduced to one-half (assuming a voltage system of 600/1200, or 750/1500) and the resistance to one-quarter of its former value, the current through this circuit will be doubled, which is the current required by the motors when arranged for low-voltage running.

The dynamotor connections are such that, when running in the high-voltage position, both windings are connected in series and the tap for lighting and control is taken from the middle point. When running on the low-voltage section the windings are connected in parallel and the tap for lights and control is taken directly from the trolley. The dynamotor connections are shown in Fig. 9.

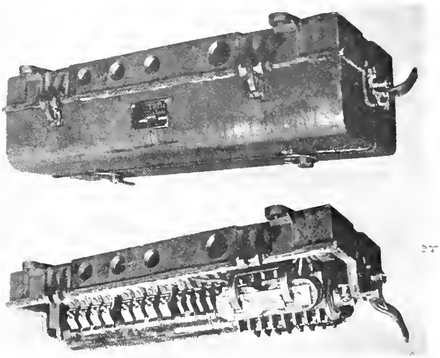


FIG. 8—CHANGE-OVER SWITCH FOR FULL SPEED ON 600 VOLTS

All other conditions remaining the same, the percentage difference in costs of control equipment of the three systems will be as follows:—

Basing the costs on a straight 1200 or 1500 volt equipment (which is considered ideal) at 100 percent, the costs of equipments for half-speed on 600 or 750 volts, and for full speed on 600 or 750 volts, will be approximately as indicated in Tables I and II. In preparing these cost percentages the change-over switches employed are all assumed to be of the hand-operated type except those used with the straight 1200 volt equipments, in which case the pneumatically-operated type shown in Fig. 1 is used.

The costs given in Tables I and II do not take into consideration control equipments employed for field control motors, as this constitutes a special case at these voltages involving a greater number of switches. For equipments running at half speed on 600 or 750 volts four extra switches are required, and for equipments running at full speed on 600 or 750 volts eight extra switches are necessary for field control.

TABLE I—PERCENT COSTS OF NON-DYNAMOTOR EQUIPMENTS

Motor Kw.	1200 Volts	Half Speed On 600 Volts	Full Speed On 600 Volts
41	100	104	113
60	100	105	115
70	100	105	122
90	100	106	124

TABLE II—PERCENT COSTS OF DYNAMOTOR EQUIPMENTS

Motor Kw.	1200 Volts	Half Speed On 600 Volts	Full Speed On 600 Volts
41	100	108	111
60	100	108	114
70	100	108	124
90	100	108	126

Although there are a great many equipments which are operated at the present time at half speed on the low-voltage section, in which case it is only necessary to change the control and lighting circuit, the general trend seems to be towards operation at full speed on the low-voltage section, in which case change-over

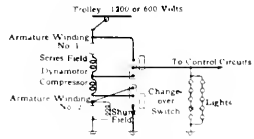


FIG. 9—SCHEMATIC DIAGRAM OF DYNAMOTOR-COMPRESSOR CONNECTIONS

switches which make the required changes in all circuits are employed. It would seem probable that eighty percent of all future high-voltage interurban equipments will be of the latter type, and that when train operation is necessary these change-over switches will be pneumatically operated.

Grid Resistor Standardization

H. H. Johnston

Electric railway companies having many different classes of car equipments in operation and have found in many cases that it would be desirable to have a fewer number of resistor layouts than at present, and many attempts have been made to adopt a standard resistor for all equipments. If the parts to be carried in stock are different for the various classes of equipments considerable space is taken up for the spare parts alone, and stock records become more complicated. The convenience in making quick repairs, brought about by a standardization of the resistors, is of more importance than a reduction in the number of stock parts, and it is with this view that operators have been attempting to reduce the number of resistor layouts to a minimum.

The resistance which should be inserted in series with the motors during the accelerating period is a function of the motor rating, the motor characteristics, and the number of motors, the trolley voltage, the gear ratio, the diameter of the driving wheels, the weight of the car or locomotive, the scheme of control, and the service requirements. If the car equipments of a railway system are alike in all respects, the resistors should be alike, and a standardization of this part of the equipment cannot be further improved.

Owing to space limitations under car bodies, the use of one style of grid in all steps of a resistor is prohibitive, as this requires additional grids and, therefore, an additional number of frames. The greater number of grids is brought about by the necessity of paralleling grids in the steps requiring higher current-carrying capacity, if a low-capacity, high ohmic resistance unit be used as the standard. On the other hand, if a high-capacity, low-resistance unit is the standard adopted, the steps of the resistor requiring low capacity and higher resistance will have excess capacity and an excessive number of grids, since the cross-section of the higher capacity grids is greater, resulting in a low-resistance unit.

The standardization of frames having the same length, or distance between mounting holes, is usually easy to adopt. However, the determining factor is the space available under the car body. The limitation due to space in most cases is brought about on small cars; however, the same condition may exist on large interurban cars where the equipment under the car body has not been mounted in the best manner. The advantages of using a standard frame length are that the different number of parts which must be carried in stock are reduced, and if the resistor frames for the various equipments are kept in stock in assembled form they can be stacked in a more orderly manner. This results in a reduction of floor space, as well as a fewer number of grids being broken due to handling of the assembled frames.

The location and number of taps or terminals on a resistor are determined by the type of control and other factors of the equipment already mentioned. If two or more equipments vary in weight, and the difference is not great enough to cause a difference in the type of motors used, or any difference in the controllers, gear ratio and diameter of the wheels, it may be possible to apply the same resistor to all equipments. However, the variation in the actual resistance in the grids from the calculated values for each equipment should not be

greater than five percent, if smooth acceleration is to be maintained by careful operation of the controller. When making up a standardization for equipments already in service a careful consideration should, therefore, be given to the accelerating conditions, and combining the terminal locations should be of secondary importance. The advantages of having the taps of a standard resistor combined to use one set of terminals are obvious, in that the minimum number of terminals is used, and there is less chance for error in making cable connections to the resistor taps. This is of particular importance where equipments having any difference in the type of control are standardized.

Before proceeding to make up a standardization in the resistors for a number of equipments in service it is necessary to be familiar with the apparatus on each car in order that the most economical application be made. If, for example, with a total of 25 equipments there are 20 equipments with resistor hangers for 22 grid frame lengths, and the remaining five equipments have hangers for 30 grid frames, the logical frame length to choose would be the 22 grid frame. However, it must be known what changes are necessary in order to apply the 22 grid frames to the five equipments, for it may be found that the cost of making the changes of hangers and other equipment, such as junction boxes, conduit and resistor taps to the main conduit, will be greater than changes on the 20 equipments to accommodate the 30 grid frames.

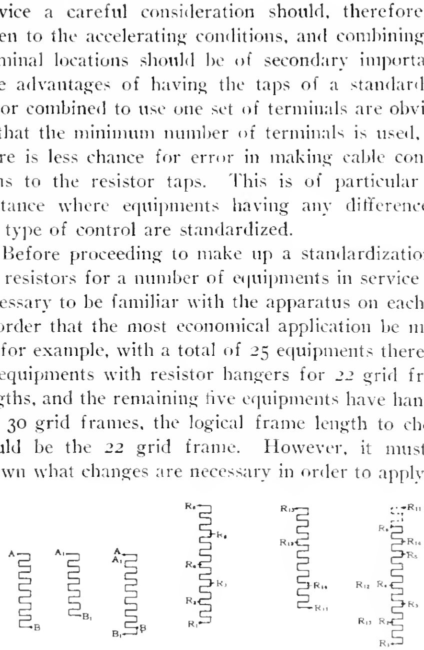


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5

Figs. 1 and 2—Method of building up resistors.
Fig. 3—Resistor layout for rheostatic controller.
Fig. 4—Resistor layout for parallel steps.
Fig. 5—Combined layout of Figs. 3 and 4

TABLE I—DATA FOR RESISTOR LAYOUTS OF FIGS. 1, 2, 3, 4 and 5.

Fig.	Section	Total Resistance Ohms	Continuous Current Capacity Amperes	Fig	Section	Total Resistance Ohms	Continuous Current Capacity Amperes
1	$A-B$	0.78*	50	4	$R_{11}-R_{14}$	0.32	43.3
2	$A-B$	0.78	50	4	$R_{14}-R_{12}$	0.35	54.8
1	A_1-B_1	0.88**	43.3	4	$R_{12}-R_{13}$	0.48	43.3
2	A_1-B_1	0.86†		5‡	R_1-R_2,R_{11}	0.32	43.3
3	R_1-R_2	0.32	43.3	5	$R_2,R_{13}-R_3$	0.24	43.3
3	R_2-R_3	0.24	43.3	5	$R_3-R_{12}-R_4$	0.24	43.3
3	R_3-R_4	0.24	43.3	5	R_{12},R_4-R_5	0.20	54.8
3	R_4-R_5	0.20	54.8	5	R_5-R_{14}	0.08	54.8
3	R_5-R_6	0.20	54.8	5	$R_{14}-R_6$	0.12	54.8
				5	R_6-R_{11}	0.24	43.3

*Resistance per grid = 0.06 ohm.
**Resistance per grid = 0.08 ohm.
†0.06 ohm per grid from A_1 to B and 0.08 ohm per grid from B to B_1
50 amperes current capacity from A_1 to B and 43.3 amperes from B to B_1.
‡Connect to R_1 R_2, R_3, R_4, R_5 and R_6 for layout shown in Fig. 4.
Connect to R_{11}, R_{13} and R_{14} for layout shown in Fig. 5.

Having determined the best frame length to adopt, the next thing to consider is the maximum number of frames required. This is arrived at by first laying out a resistor in some convenient diagrammatic form for all equipments involved. Each layout should employ the fewest number of different grid styles possible. After this has been done it is best to combine the layout having the greatest current capacity in the various steps with the one having the greatest total ohmic resistance. It will usually occur that the resistor having the highest capacity will have the lowest total resistance. The two layouts just combined can then be combined with the layout having the next highest capacity, etc.

This method of procedure is continued until all of the resistor layouts are combined, consideration having been given to the thermal capacity required in the various steps and to the type of control, or method of cutting out the resistor steps. If the same general scheme of control is used on all equipments, it is generally found possible to follow one method of building up the standardization, that is, in cases of rheostatic notching, after having started with the highest capacity resistor, each succeeding layout may be added to the previous combination by working from the high capacity or low resistance steps toward the low capacity or high resistance steps.

A simple illustration of this method of building up the standardization is shown in Figs. 1 and 2. In this case two single-step resistors are combined and, as shown in Fig. 2, A_1-B_1 is made up of the grids $A-B$ of Fig. 1 plus one more grid of the same capacity used in A_1-B_1, Fig. 1. If more layouts were to be combined with these, they would be combined with these two in a similar manner; taking, as the next layout to be combined, the one having the next highest capacity.

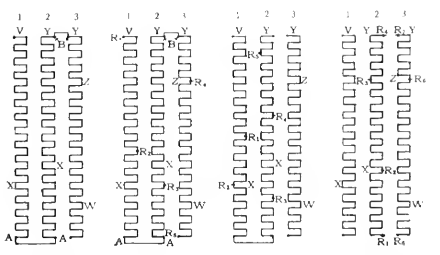


FIG. 6 FIG. 7 FIG. 8 FIG. 9

Fig. 6—Standardized resistor layout for all the classes of equipments.
Fig. 7—Resistor classification A.
Fig. 8—Resistor classification D.
Frames 1 and 2 only are required.
Fig. 9—Resistor classification K.
Frames 2 and 3 to be used and no jumper connections required.
V, W, X, Y and Z represent different standard grid sizes

If instead of having but a single step, the layouts shown in Figs. 1 and 2 had another step, B to C and B_1 to C_1, respectively, then B to C (if it were the next higher capacity step) would be combined or added to $B-B_1$ in a manner similar to that used in combining A_1-B_1 and $A-B$.

Where paralleling of the various steps is involved, a building-up of these layouts from both the high and low capacity ends is usually required. Figs. 3 and 4 illustrate a resistor layout for a rheostatic controller and for

a type of control which parallels the steps while accelerating the equipment. The best combination of the two layouts will result if R_{12} is made to coincide with R_4 and the step R_{12}–R_{13} built up from the grids between the steps R_4 to R_1 of Fig. 3. R_{12}–R_{14} can then be built up from the grids in the steps from R_4 to R_3. R_{14}–R_{11}

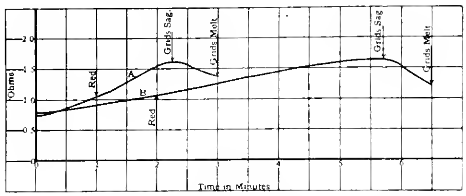


FIG. 10—MELT-DOWN TEST ON TWO GRID ASSEMBLIES

Having same cold resistance and continuous capacity, but differing in thermal capacity; 275 percent continuous rating current passed through grids with grids having a temperature of 23 degrees C. at start and having natural ventilation throughout test.

is then made up by using the remaining grids in R_1–R_2 step and, by adding the necessary number of grids of the proper capacity to secure the necessary resistance. Fig. 5 shows the two layouts combined and illustrates how the layout in Fig. 4 was built, mostly from the grids in Fig. 3, by beginning at the lower capacity end of the latter layout.

Where the scheme of control varies for nearly all equipments, no well-defined rule can be followed in building up the standardization and a cut-and-try method will usually give best results.

TABLE II—GRID RESISTOR STANDARDIZATION

Resistors classified according to location of terminals.

Class of Equipment	Motor HP.	No. of Motors	Gear Ratio	Wheel Dia. In.	Wght of Car Tons	Type Control	Resistor Classification
1	38	2	15:69	33	12.5	K-10	A
2	38	2	15:69	33	18.5	K-10	B
3	40	2	17:69	33	17.2	K-11	C
4	70	2	18:69	33	18.5	K-11	C
5	60	2	16:71	33	10.	K-36	C
6	25	4	21:62	33	20.	K-12	D
7	50	4	24:63	34	32.	K-14	E
8	50	4	21:64	33	28.5	K-14	E
9	50	4	21:66	34	29.	K-14	E
10	50	4	16:69	33	30.	K-14	F
11	40	4	17:69	33	32.	K-28	G
12	40	4	25:61	34	26.5	K-28	G
13	40	4	17:64	33	20.5	K-28	H
14	38	4	15:69	33	19.5	K-28	H
15	38	4	17:69	34	24.	K-28	H
16	40	4	22:64	34	25.5	K-28	J
17	40	4	22:64	33	25.	K-28	J
18	40	4	22:64	34	27.	K-35	K
19	40	4	19:67	34	27.5	K-28	L
20	40	4	15:69	33	21.	K-28	M
21	40	4	17:69	33	30.	K-28	M

The data given in Table II is typical for a standardization of 21 classes of equipments. For these equipments a standardization of the grid resistors has been made up, which makes it possible to have one standard layout, consisting of three standard length frames and a total of five different styles of grids. The standard layout ready to locate the terminals for the various resistor classifications is shown in Fig. 6, while Figs. 7, 8 and 9 show the terminals located as required for classifications *A, D* and *K*. The layout of the other classifications is made in a similar manner, and when the terminal locations have been determined for all the classifications they can be located by the shop men by referring to the terminal location charts, kept in a convenient place for reference.

From Figs. 7, 8 and 9 it is evident that all of the grids in the standard layout are not required for all the classifications, as, for example, *D* and *K*, while *A* makes use of all the grids. In *D* frames No. 1 and No. 2 are used, while in *K* frames No. 2 and No. 3 are required.

In making up a standardization for many widely different equipments it will often be found impossible to make one layout suitable for all the equipments involved, and two or more standard layouts will be necessary.

The thermal capacities of grid units of different manufacture differ somewhat, and grids having the same continuous current-carrying capacity, but with sufficiently different thermal capacity, may cause trouble in a standardization if the continuous ratings are followed. This brings up the question of service conditions and the consideration of peak loads in choosing grids of the proper capacity. A check on the thermal capacity of the grid units can be made by reference to their weights per ohm; the thermal capacity being directly proportional to the weight. The importance of thermal capacity can be seen from Fig. 10, which shows the increase in resistance and points of distress and failure of two grids having the same continuous capacity, but differing in thermal capacity. A current of 275 percent of the continuous rating was passed through both grids and the condition of the grids noted at half-minute intervals. The grids having the higher thermal capacity showed color two minutes after the start of the test, while the grids of lower thermal capacity showed color in half this time.

Under the subject of standardization may be considered a standard method of making repairs. If no standard or systematic method of making repairs is adopted it will be only a question of time until the resistors are in a poor condition. In going over a number of resistors in service it is not unusual to see a number of grids of different capacity in one or more of the steps of the resistors. This condition should not exist if a standard method of making repairs has been adopted and the arrangement of the grids as supplied by the equipment manufacturer is followed. The poor condition of the resistors will usually show up in the form of poor acceleration of the equipment and, if grid replacements are made without considering capacities, the poor condition will show up in the form of burnouts of the grids of too low capacity.

Operation of Philadelphia-Paoli Electrification

OF THE PENNSYLVANIA RAILROAD

W. H. Thompson and L. E. Frost

ELECTRIC trains were first placed in service on the Philadelphia-Paoli electrification of the Pennsylvania Railroad in September, 1915. During the first few days of electric operation two groups of cars were used. One group made one round trip per day between Philadelphia and Paoli, and the other made three round trips, a total of eight electric trains. The local steam trains were taken off gradually until the latter part of October, when the entire local service of 68 trains per day had been transferred to the electric schedule. The running time was reduced five minutes westbound and one minute eastbound, when the last local steam train was taken off. A month later the five morning and five evening local expresses were added to the electric schedule. In May, 1916, a new schedule was adopted, in which there are 85 trains per day, and in which an additional reduction in running time of three minutes westbound and two minutes eastbound was made. This schedule is in effect at the present time. The shortest train has two cars; the longest, eight or nine, while the average train length is four cars.

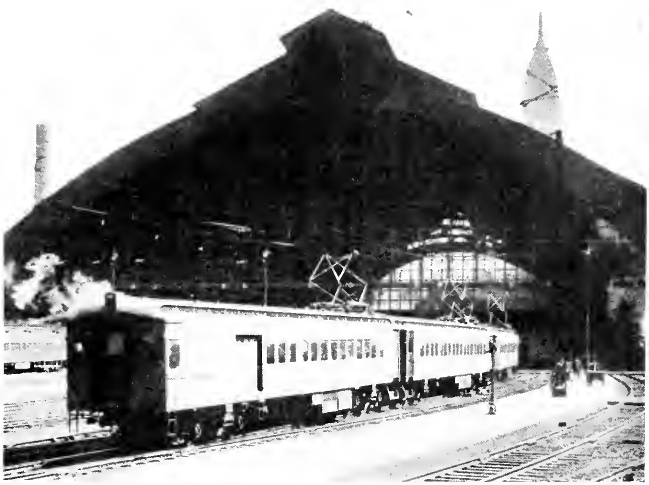


FIG. 1—ELECTRIC TRAIN LEAVING BROAD STREET STATION, PHILADELPHIA

The main line running into Broad Street terminal constitutes one of the busiest sections of steam railroad in the United States. Nevertheless, the construction work of installing the catenary system was successfully accomplished without interference with traffic, and since its completion the electric trains operate over the same tracks used by the steam trains without the slightest interference. The adoption of 11 000 volts made it possible to use an overhead system of contact wires which is of such light and simple construction that the visibility of the signals is not interfered with and, therefore, the steam trains for through passenger and freight traffic are operated over the electrified sections without any disadvantages due to the electrification.

The motor cars are the standard steel cars which have been in use for several years for steam-operated suburban service. The electrical equipment was mounted on these cars with practically no changes with the exception of adding a platform end door for the motorman's compartment, the substitution of a motor truck for one of the standard trucks and changing the lighting and heating system to be supplied from the trolley.

Each car is a motor car and no trailers are used; therefore, the amount of power which can be supplied to accelerate a train is very much greater than that which can be supplied from even the largest steam locomotives, as the power available is only limited by the capacity of the power station, substations and transmission lines. Some long heavy trains may require 6000 horse-power for a short period during acceleration. It is evidently beyond the range of practicability to supply this amount of steam locomotive capacity to one of these trains and the result is, therefore, that the acceleration and resulting schedule speed of these heavy trains is far in excess of that possible with the Pennsylvania Railroad's largest locomotive.

Another important advantage of these multiple-unit cars is their individual mobility and double-end operation, which allows quick turn-around at terminals and saves time in making up trains. This means that it is possible to operate each car for a great number of car-miles per day and, consequently, a less number of cars are required for the service than under steam operation. Individual cars make as high as 240 miles per day, and 53 cars are required for the service of 85 trains per day, exclusive of those which may be undergoing inspection or repairs. In the eleven months of operation these trains have already run up a car mileage of about two million miles.

The principal object of this electrification was to relieve the congestion which existed at Broad Street sta-

tion, Philadelphia. This terminal was subject to congestion, due to the fact that it is of the "stub-end" type, and the 16 tracks in the train shed converge a short distance outside to six tracks at the "throat," over which all trains entering or leaving the station must pass. A train hauled by a locomtive enters the train shed to discharge passengers. Before the cars and engine can be used again for another train the cars must be pulled out, the engine backed out and turned around, the cars backed in, and the engine backed in. This involves a large number of movements in and out of the train shed, each of which must be past the first signal, which is located at the throat. As such a movement may block three tracks, it was very difficult to make the number of movements necessary, and also allow the passage of incoming and outgoing trains without delay. Once a delay was started during a rush hour it became cumulative, and could not be eliminated until the rush hour was over.

With steam-operated trains the average number of movements before the cars can leave as another train is six, as follows:—

1—Shifting engine enters train shed.
2—Shifting engine pulls cars out of train shed.
3—Road engine backs out.
4—Shifting engine pushes cars into train shed.
5—Shifting engine leaves.
6—Road engine backs into train shed.

With multiple-unit operation all of these movements are eliminated. In addition to the relief which this affords to the throat congestion, it reduces the track room required inside the train shed, due to the quicker turn-around which is possible with the electric trains. The increase in terminal capacity resulting from multiple-unit operation of the 85 Paoli trains has improved the entire service into and out of Broad Street station. The improvement is due not only to a reduction in the number of switching movements in the approaches to the terminal, but also to the greater mobility of the electric trains, owing to better acceleration. The advantages of electric operation are particularly noticeable to the operating force which has to do with the handling of the trains. The men who make up this force thoroughly appreciate these advantages. With the additional electrification of the Chestnut Hill branch, on which there are 64 trains per day, the benefits will be proportionately increased. It is estimated that the relief obtained due to electrification will then amount to 23 percent in the morning and 24 percent in the evening rush hours.

FIG. 2—TRAIN OF SINGLE-PHASE MOTOR CARS PASSING SIGNAL BRIDGE

While the prime object of this electrification was to relieve the congestion in Broad Street station, it has also resulted in a great benefit to the Pennsylvania Railroad, and the main line patrons, by improving the service. A most important territory is served by the electrified portion of the main line. With the exception of the first five miles of congested part of Philadelphia, the route is through a prosperous residential district, containing many wealthy homes, beautiful country estates and colleges. The class of patronage, therefore, is one which requires a service of the highest standard. How well this demand has been met is shown by the fact that although an average of 20 000 per day, or 7 000 000 passengers per year, are carried in this service, complaints received by the railroad company in a year do not exceed 25.

The electrification benefits the patrons by providing better schedules and by operating trains with fewer delays. In the twenty miles from Philadelphia to Paoli the local trains make 19 stops, and the local expresses make 14 stops. There is a rise in elevation of 500 feet from Philadelphia to Paoli. The running time of the local trains during steam operation was 57 minutes westbound and 50 minutes eastbound. In October, 1915, when the entire local service was made electric, these running times were reduced to 52 and 49 minutes, respectively. In May, 1916, another reduction in running time was made, to 49 minutes westbound and 47 minutes eastbound. With the electric operation of the local expresses the steam schedule has been improved by five minutes westbound and by about three minutes eastbound, the running times now being 44 minutes and 41 minutes, westbound and eastbound, respectively.

The heavy evening trains, when operated by steam, were never able to make schedule time, owing to slow acceleration. These trains, operated electrically, accelerate just as rapidly as the smaller trains, as each car is a motor car and consequently the schedule of all trains is now usually followed closely.

POWER SUPPLY

Single-phase power for this electrification is purchased from the Philadelphia Electric Company. Current is received at 13 000 volts at the Arsenal Bridge transformer station, where it is stepped up to 44 000 volts. At this pressure it is transmitted to the three step-down transformer stations, at West Philadelphia,

Bryn Mawr and Paoli. In these latter transformer stations the voltage is transformed to 11 000, the trolley voltage.

Until the Chestnut Hill electrification is completed it was anticipated that some special means would be required during the morning and evening rush hours in order to insure proper voltage regulation on the trolley feeders. Therefore, a temporary installation of switches was made for accomplishing the desired result by changing the number of turns of the low-tension windings of the step-up transformers at Arsenal Bridge. Taps were brought out of the transformers so that the ratio of transformation could be altered by changing from one set of taps to another. The device has come to be known as the "tap-changer." Electro-pneumatically operated oil switches are used. The control is automatic, and is operated by a compensator, such as are used with other types of regulators. Interlocks are provided to prevent improper operation of the switches.

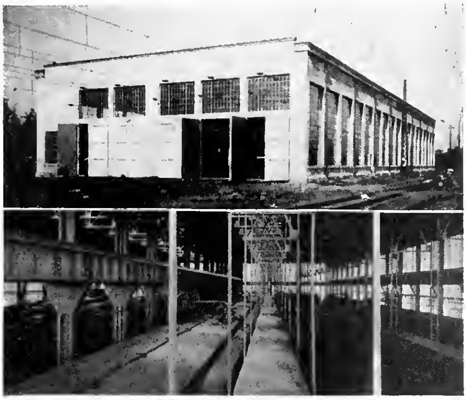


FIG. 3—PAOLI CAR BARN

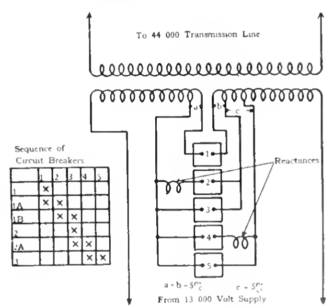
Containing five tracks, each long enough to hold four cars. The inspection work on the Chestnut Hill cars will be done at Paoli, when the electrification of the branch is completed. The interior view at the bottom shows the pantagraph inspection arrangement.

EQUIPMENT PERFORMANCE

The electrical apparatus of the multiple-unit cars is cooled by a blower fan, which delivers about 6000 cubic feet of air per minute. During heavy snowstorms the first winter, considerable snow was taken in with the cooling air. For a time this threatened to be a serious trouble, because the melting snow in the transformers impaired the insulation and caused a number of transformers to develop grounds. The air intakes for the fans were on a line with the side of the car and faced outward. As a temporary expedient, cheesecloth was placed over the intake of all cars. This proved to be an effective means of keeping the snow out of the electrical apparatus. As a permanent cure for the trouble the intakes have been changed so that the air is taken in through openings located underneath the car body, in a position comparatively free from moisture. In addition to this, the insulation of the transformers has been made more moisture-proof by dipping the transformer as a whole in a water-proof varnish, and baking. A transformer which had had this treatment was subjected to a test in which water was sprayed into the ventilating air at the rate of 32 cubic inches per minute, for one hour, without impairing the insulation.

During the early months of electric operation several pantagraphs were wrecked. This trouble was overcome by adopting a stronger end horn and by slight modifications and adjustments in the overhead line.

The cars have the blower fan and the air compressor combined in one outfit. One motor drives the fan continuously and the compressor intermittently. The latter is cut in and out by a clutch, which is operated by the governor. The single-phase, doubly-fed motor which is used in this set has the speed characteristics of the ordinary series motor; consequently, the fan is operated at two speeds. In order to deliver the required average quantity of ventilating air it is necessary to operate the fan at the rather high speed of 1400 r.p.m., with the compressor cut out. With the compressor cut in, the speed is 1000 r.p.m. The diameter of the fan is about 21 inches. It was found at the very beginning of electric operation that the fans which were originally furnished with the equipments were not strong enough to stand the severe service conditions imposed by this set. The high maximum speed and the sudden speed changes caused by the cutting in and out of the compressor, together with the vibration due to the latter, caused excessive strains, which resulted in one or two broken blades. This in turn threw the fan out of balance, thereby aggravating the trouble. The vibration caused by the unbalanced fan was transmitted to the car body, and was therefore objectionable. In order to get best results it was necessary to balance the fans dynamically. The new fans were balanced with the Akimoff dynamic balancing machine with great success.



	1	2	3	4	5
1	×				
1A	×	×			
1B		×	×		
2			×		
2A			×	×	
3				×	×

FIG. 4—APPLICATION OF "TAP-CHANGER" TO A STEP-UP TRANSFORMER

Steps *1*, *2* and *3* are operating positions; other steps are transition positions.

New Motors for Old

SOME CONSIDERATIONS ON THE RETIRING OF OBSOLETE RAILWAY MOTORS

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An obsolete motor costs, say, $2.50 per thousand miles to maintain. A modern motor costing, say, $400 can be maintained for $0.30 per thousand miles. A trolley car can average 35 000 miles per year. Then:—

$2.50 — $0.30 = $2.20 saving per thousand miles;
$2.20 × 35 = $77 saved per year;
$77 ÷ $400 = 19.25 percent of the first cost.
The new motor pays for itself in five years.

While these individual statements may each be perfectly true, the answer to the problem involves so many considerations, other than this simple arithmetic, that a proposition to retire and replace motors on old cars deserves more careful analysis than perhaps any other project involving the expenditure of new money. There are many cases, however, where such an analysis will show that such motors may be profitably replaced by new motors of modern design.

In considering the replacing of motors on a certain class of cars one question to be considered is,—what is the service capacity, age and condition of the car body and trucks? Even if the old car is "good for twenty years more" it may be too heavy for the seating capacity and at the same time not large enough or suitably equipped for modern traffic requirements. If the cars give promise of a further useful life of but four or five years, consideration must be given the question of what can be done with the new motors when the old cars are worn out.

Another point to be considered is the mileage that can be gotten out of the cars without sacrificing economy in operation. In the street railway industry, as in the central station field, the shape of the load curve controls the relative importance of fixed and operating charges. In the language of the street railway men, the peak load is the evening rush hour, and what corresponds to the term load factor is the average number of cars in service divided by the maximum.

It is safe to assume that the average road will have 90 to 95 percent of all its cars in service at 5 P. M., on special occasions such as national holidays, municipal celebrations and baseball days. However, it is probable that 80 percent of the total annual mileage could be performed by 60 percent of the number of cars actually on hand. The other 40 percent of the cars stay in the barns until they are needed for the rush hour. Obviously a given operating economy per car-mile obtainable on these reserve cars cannot be capitalized at the same value as on the cars which work throughout the day.

A street railway property of any considerable size will usually have several classes of cars, the oldest dating back 12 or 15 years and other types coming along at intervals of two to five years until the new cars are reached. The later types are naturally better suited for present-day traffic, and the aim of the operating man is to use the new cars as much and the old cars as little as possible. The combination of an obsolete and inferior design, old age (often supplemented by overloading and neglect in past years) and low mileage sometimes forces up the unit cost of maintenance to the distressing figure of four or five dollars per thousand car-miles.

Take, for example, the case of a large urban property having five principal types of motor equipments,—the size, age, average mileage and maintenance costs for the year 1914 being given in Table I. The high unit cost of maintaining the old Type A motors offers an excellent opportunity for replacement with modern motors, but probably the new motors would not make these cars suitable for any higher annual mileage. Assuming 30 cents per thousand miles for the new motors, the apparent annual saving would be:—

TABLE I—RESULTS OF MOTOR OPERATION

Motor Type	HP at 500 Volts	Average Age in Years	Average Miles per motor per year	Average maintenance per thousand miles
Type A	30	14	5200	$5.10
Type B	35	14	11800	3.23
Type C	60	10	24700	2.29
Type D	60	7	35000	0.76
Type E	60	2	36800	0.11

For the replacement of the Type A motors, $4.80 × 5.2 = $24.96;
For the replacement of the Type B motors, $2.93 × 11.8 = $34.60;
For the replacement of the Type C motors, $1.99 × 24.7 = $49.10.

It therefore appears that if, in future years, the same relative mileage should obtain, other things being equal, the most favorable proposition would be the replacement of the Type C motors, even though the first cost of the new motors would be greater in this case than for other new motors to replace the smaller Types A or B motors.

The mileages in Table I are the average of all motors of each type and, in the case of the Type A motors, the number of motors upon which the records are based corresponds to approximately 100 cars. A knowledge of the local conditions might change the conclusion ap-

parently indicated in the preceding paragraph; it might be that the replacement of the Type A motors on a part of these 100 cars might enable a large part of the maximum possible maintenance saving to be realized with a comparatively small investment. It might be found that 25 of the 100 cars of this class were required for the regular daily schedule, the other 75 cars being used principally during the rush hours. Assume that 30 of the total number of cars are selected as having the best bodies and trucks and are equipped with new motors (60 of the old motors being scrapped), and an average of 10 000 or 15 000 miles a year obtained with the 60 new motors (these being double equipments). This replacement would increase the saving per year for each new motor from $24.96 to $48 or $72, respectively.

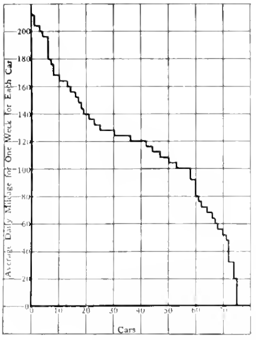

FIG. 1—INDIVIDUAL CAR MILEAGE FROM ONE WEEK'S RECORD

75 cars totaled 63 000 miles.
20 percent of the cars made 30.3 percent of the mileage.
40 percent of the cars made 53.2 percent of the mileage.
60 percent of the cars made 71.0 percent of the mileage.
80 percent of the cars made 90.0 percent of the mileage.
(Cars making no mileage omitted).

The curve shows the unequal division of mileage existing even among cars of the same age and class and in the same service. This is unavoidable because of the variable nature of railway traffic. When different classes of cars are available, and certain of these are more economical than others, advantage can be taken of this fact by using the more economical cars on the runs of highest daily mileage.

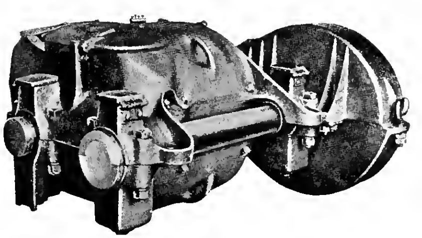

FIG. 2—AN OBSOLETE TYPE OF MOTOR

This motor weighs about 2400 lbs., and if not overloaded can be replaced by the 1700 lb. modern ventilated motor shown in Fig. 3.

The maintenance cost of any motor depends directly on the work it has to perform. The most up-to-date types are expensive to maintain if overloaded in service. Many of the obsolete types have given satisfactory results where the loads and schedules have not worked the motors very hard. On replacement propositions the car weights, the schedules, number of stops and the operating temperatures of the old motors should be carefully studied and the selection of a motor of adequate capacity and suitable gear ratio should be made on this basis rather than from a blind matching of ratings of the new and old motors. In some cases, by slightly increasing the speed, a given route may be operated with a smaller number of cars and crews, with a consequent saving sufficient to counterbalance the increase in power consumption. However, the old motors will often be found to be geared for speeds higher than are necessary for the most efficient schedules; thus, in selecting the new motors, advantage should be taken of this point, which results in further reduction in size and cost of the new motor and in power consumption.

Even if the old motors are none too large in rating, their replacement does not necessarily require that the new motors must have the same nominal horse-power or weight. In fact, the tremendously greater service capacity (continuous rating) per pound of weight, obtainable with modern ventilated motors, makes possible a considerable operating economy through the saving in power. For equal service capacity, the weight of a modern ventilated motor is from 60 to 85 percent of the weight of the old-style totally-enclosed motor; the percentage itself depending upon the commercial sizes and speeds available. If the old motor weighs 2700 pounds, and is replaced by a motor weighing 2000 pounds, the saving for a two-motor equipment would be 1400 pounds. At an assumed operating cost of one cent per pound for every 10 000 car-miles, there would result an annual saving of from $7.30 to $51.50 per car (using both minimum and maximum mileage figures from Table I).

FIG. 3—MODERN LIGHT-WEIGHT, COMMUTATING-POLE, VENTILATED MOTOR

In case the old motors are used in quadruple equipments it is sometimes possible to replace them with equipments of two motors of a larger size, thus obtaining new motors at the minimum cost and having minimum weight, power consumption and maintenance (per car-mile). A replacement of this kind was recently undertaken by a suburban road having light grades, a moderate schedule and traffic which, while extremely heavy in the summer, dropped to a very small figure during the winter months. The rolling stock consisted of 20 cars, each equipped with four 50 hp motors. The maintenance cost of these old motors was excessive, due

partly to overheating in summer, and it was assumed that a replacement would involve four new motors of larger capacity for each car. It was planned to place the new motors first on six cars and on six or ten additonal cars later, and to use these cars for the greatest possible proportion of the total mileage. After investigating the problem, it appeared that there was practically no objection from the operating standpoint to the use of two-motor equipments, which gave a saving of $500 per car in first cost. From 2500 to 3000 pounds weight would also be saved with the two-motor equipment, as compared with a new four-motor equipment. The weight reduction per car compared to the old four-motor equipments amounted to 5700 pounds.

If the cars are used in city service, with frequent stops, a careful analysis of the replacement problem shows that it is profitable to retire parts of the old control equipments as well as the motors, so as to obtain the advantages of field-control motors, as well as to secure the benefits of their lower maintenance costs and the greater reliability of the control equipment itself. In addition to the power saving obtainable with this type of motor, the reduction in heating for a given service often makes possible the use of a field-control motor which is smaller and lighter in weight, thus still further increasing the power saving. The cumulative effect of these factors makes a comparison of the power consumption of the old four-motor equipments and the new ventilated two-motor field-control equipments seem truly startling.

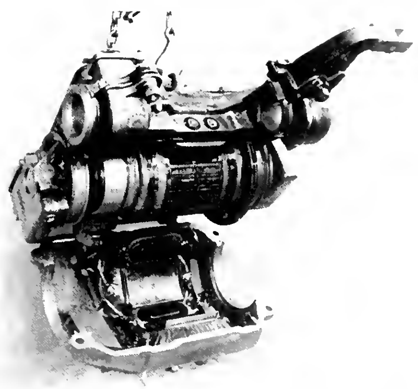

FIG. 4—TYPICAL LIGHT-WEIGHT VENTILATED MOTOR
Showing ventilating fans and commutating poles.

Recently a similar problem involved a city car line normally using 45 cars which were equipped with quadruple 30 hp motors of an obsolete type. It was decided that four motors per car were necessary because trailers were used during rush hours. Later it developed that this trailer operation required only four or five cars of this particular type and therefore the main proposition for replacement of the motors of 45 cars need not be handicapped by this minor element. The operating company considered two schemes, one the replacement with two motors of the non-field-control type, the other involving field-control motors and new controllers. The saving in weight amounted to 3800 pounds per car, which would reduce the power required by 8.5 percent and, with a slightly lower speed gearing on the two-motor equipments, would effect a further saving of two percent, giving a total saving of 10.5 percent for the non-field control motors. It was further estimated that the field-control motors would make the total reduction in power consumption amount to 17.5 percent. In this particular instance the railway company finally, however, accepted the non-field-control proposition to avoid the additional expense of replacing the controllers.

In still another case, involving a comparison of cars of different weights and where the four-motor non-field-

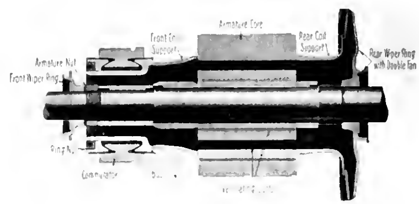

FIG. 5—SECTION THROUGH VENTILATED MOTOR

Figs. 4 and 5 illustrate the modern method of ventilation, which increases the continuous ratings of railway motors 40 percent over what can be obtained with totally enclosed motors.

control motors were geared for higher speed than necessary for the schedule, the saving due directly to the new type of equipment amounted to 29 percent of the total power used by the old quadruple equipments. The saving in weight of the two-motor equipment amounted to 9.5 percent, while the remaining 19.5 percent is credited directly to the combined effect of slower speed gearing and field-control motors. This probably represents the maximum saving obtainable without sacrificing schedule speed and applies only to city service with frequent stops.

It is evident, therefore, that the replacement of obsolete motors is well worth a thorough investigation, and that the consideration of maintenance reduction alone does not cover the full possibilties of obtaining the greatest return on the investment.

Maintenance of Railway Equipment

A DESCRIPTION OF THE METHODS IN USE AT THE REPAIR SHOPS OF THE CLEVELAND RAILWAY COMPANY

A. B. Cole

SAFETY and reliability of service are among the prime requisites of operation of an electric railway. They depend on the initial selection of reliable equipment and its proper inspection and maintenance. The fact that modern railway companies appreciate that much depends on suitable facilities and shop equipment for the maintenance of railway apparatus is well illustrated by the careful attention which is being paid to these features in the more recently constructed operating and repair stations, of which the shops of the Cleveland Railway Company form a typical example.

THE maintenance of equipment of the Cleveland Railway Company comes under the jurisdiction of its mechanical department. Practically all of the routine inspection and light or running repairs are made at fourteen operating stations and barns which are scattered throughout the city, all cars being given a light inspection every three days. The cars are washed on the outside every three or four days and are thoroughly washed on the inside every two months, in addition to the usual sweeping and dusting which is done each night.

The operating stations are planned for the double purpose of serving as running repair shops and of furnishing division headquarters for the convenience and welfare of the trainmen and the operating officials. The repair shops are divided into inspection, car-washing and repair sections and stock rooms. The Superior Avenue station has a somewhat larger repair shop than the others, as it is intended to be used as a branch to the Harvard shops. Light repairs to cars are made at the operating stations. In connection with each station there is a large outdoor loop yard for storing cars.

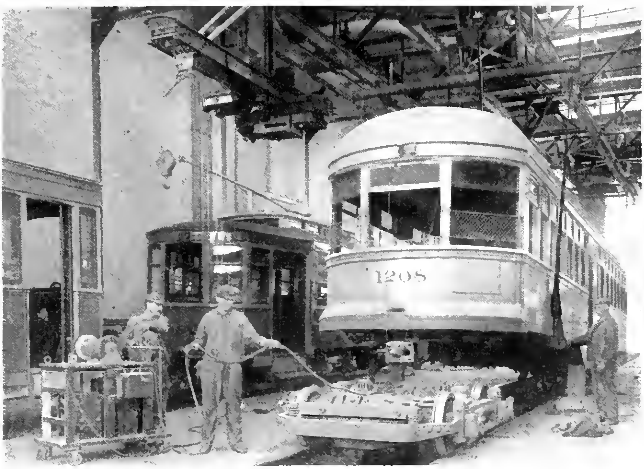

FIG. 1—USE OF PORTABLE CONTROL RACK FOR RUNNING TRUCK OUT FROM BENEATH THE CAR UNDER ITS OWN POWER

THE HARVARD CAR SHOPS

The Harvard shops are located about four miles from the business center of Cleveland, at Harvard Avenue and Forty-ninth Street, this being approximately the center of distribution of the system. As shown in the plan of the shops, Fig. 2, about one-half of the entire property of 40 acres is covered by shop buildings. The shops are of sufficient capacity that from 1500 to 1600 cars can be overhauled annually. Track connection is provided with the Newburgh & South Shore Railroad, which permits the delivery of materials directly to the shops.

All heavy repairs are made at the Harvard shops, including work on motors, trucks and car bodies. Each car was until recently given a complete overhauling once every eighteen months, or whenever it required painting. At present, however, cars are being shopped for general overhauling annually. In addition to overhauling and repairing a large number of cars, new types of cars are completely designed, developed and built at the shops;—before a new type of car is ordered in quantities, a sample is first built at the Harvard shops which is thoroughly tried out in service. In addition to this work, large numbers of old cars are completely reconstructed.

The shop buildings are arranged in two rows, separated by a transfer table pit. All shop tracks, of which there are 35 on one side and 36 on the other, are intersected by the main transfer table pit except for two at the north end and one at the south end of the shops. This pit contains two transfer tables, one of 25 tons capacity, for handling street railway equipment, and one of 75 tons capacity, for shifting loaded cars of coal or other heavy material either to the heating plant or to the various shop buildings and tracks, each table being driven by a 40 horse-power motor. All tracks are built of 80 pound rails laid on wooden ties, and in order to permit the free movement of men and equipment across the tracks outside the building the entire area is filled

with limestone screenings up to the rails. In addition, the truck shop is served by a 25 ton transfer table used for routing work, and a similar transfer table is provided opposite the erecting shop.

The office of the master mechanic, which is in the administration building, serves also as quarters for the company's first aid department. The scheme of administration is shown in Fig. 3.

THE MOTOR SHOP

When a car is turned in for repairs and the trouble cannot be located by the usual inspection methods, it is tested out by means of a testing box connected by temporary contacts to the controller. This test equipment consists essentially of a set of ratio resistance coils, a set of standard resistance coils arranged in convenient steps, a battery of small cells to supply the test current, a sensitive galvanometer calibrated to read resistance directly, and keys or switches to control the circuits. These parts are permanently connected to make up a modification of the Wheatstone bridge. The operator knows from previous experience the normal resistance of the various circuits, and by checking these values is able to locate the faulty circuit. This test will locate broken grids, loose connections in wiring, short-circuits, open circuits and grounds in motor and car wiring.

Removing Motors from Trucks—When it becomes necessary to remove a motor for repairs, it has been customary to remove the king pin and lift the body by means of an overhead crane. The motor leads are then disconnected and the truck pushed out from under the car by the workmen. This procedure is inconvenient, as it is necessary for the men to do considerable work under the suspended car body. In Fig. 1 is shown a method of running the trucks out from underneath the car body, using the motive power of the motors on the trucks. This is made possible by the use of a portable control rack, on which is mounted a controller, grid resistors, circuit breakers and a cable reel that carries the cables leading to the motors. Connection is made

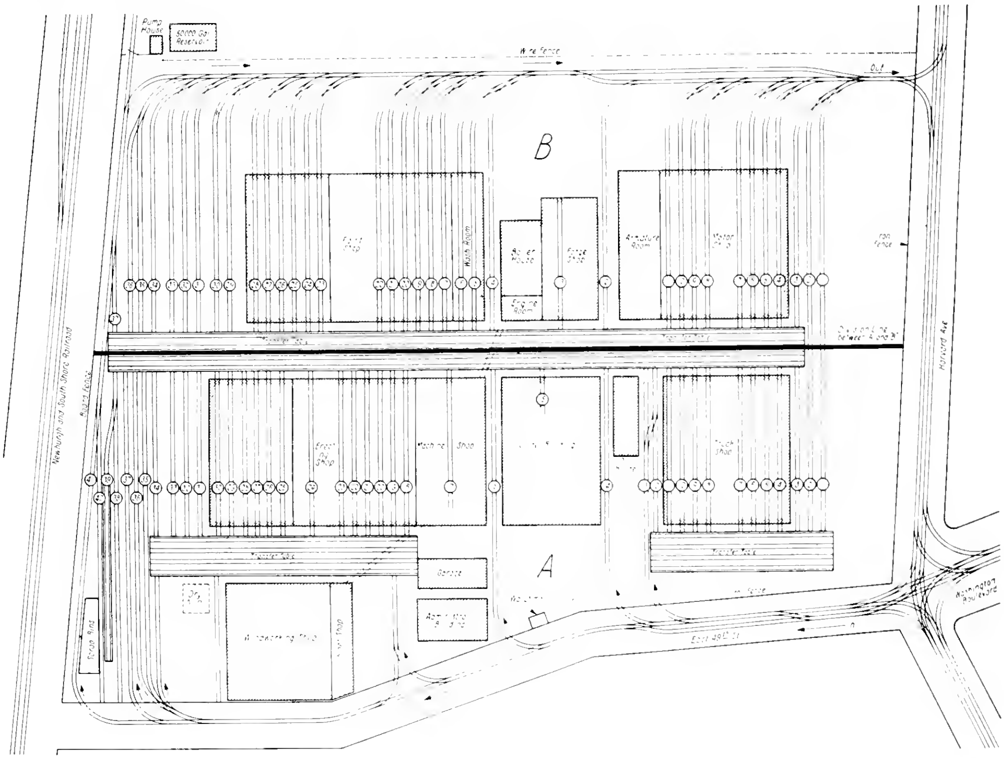

FIG. 2—LAYOUT OF HARVARD SHOPS

Department	Area	Per Cent of Total Area
Truck shop	20 072 sq. ft.	10 7
Motor shop	38 450 sq. ft.	14 7
Blacksmith shop	10 221 sq. ft.	3 7
Paint shop	54 096 sq. ft.	20 1
Machine and erection shop	62 928 sq. ft.	23 5
Wood-working shop	22 294 sq. ft.	8 3
Storehouse	51 078 sq. ft.	19 4
Total	268 145 sq. ft.	100 0

Department	No. of Men Employed
Office	10
Mill and Cabinet	31
Carpenter shop	139
Machine shop	74
Paint shop	80
Motor shop	62
Truck shop	42
Blacksmith shop	15
Electric welding and babbitt room	5
Storeroom	15
Miscellaneous	55
Total	533

from the trolley wire through the portable control outfit to the motors by means of a small terminal board on the end of the cables. When a car body clears the trucks and the motor leads are properly connected to the terminal board of the outfit, the circuit breaker and controller handle are operated and the motors run the truck out from under the car without the element of danger to any of the workmen. After the truck is run out from under the car body, the body is lowered onto blocks placed on the floor, so that the crane can be released for other duties. The motor suspension bolts, axle caps and gear case are then removed and the traveling overhead crane picks up the motor and carries it to the motor repair aisle.

Where only one motor is to be repaired and it is not desired to remove the truck from under the car body, a box frame motor may be removed by the method shown in Fig. 4. A pit jack is run under the motor, and is raised to support the motor weight. The axle caps, gear

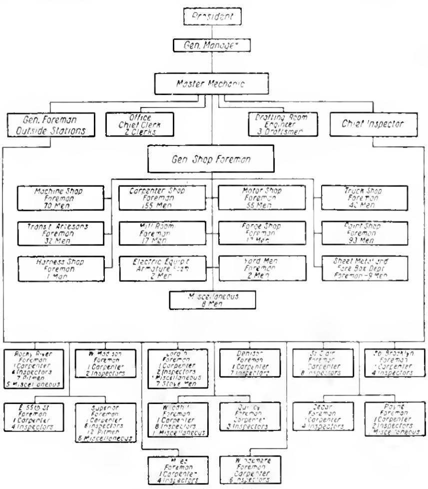

FIG. 3—ADMINISTRATION LAYOUT

case, suspension bolts and the bolts from one end of the truck suspension bars are removed and it then becomes possible to swing the entire motor around the axle and lower it into the pit. The pit jack is then pushed out from under the car and the motor lifted by means of the overhead trolley crane, as shown in Fig. 5.

When it is desired to remove an armature from a split frame motor without removing the motor from the truck, the motor frame bolts are removed to allow the lower half of the shell to swing down and out from under the armature. The pit jack is then run under the armature and raised to support it while the housing bolts in the upper shell are removed. The armature is then free to be lowered into the pit by means of the hydraulic jack on the pit trucks. The armature can then be removed by the crane or lifted to the floor level and carried away in a hand armature truck of the type shown in Fig. 6. This type of truck is used throughout the shops wherever it is necessary to transfer armatures.

To remove the lower half of the motor frame and the armature as a unit the pit jack supports the motor weight while the motor frame bolts are removed, after which the motor shell with the armature is lowered onto the pit truck. The truck is then pushed along the pit track until the lower shell and armature can be hoisted by the jib crane.

Motor Repair Section—After the motors have been removed from the truck it is advisable to remove all of the dirt and grease before disassembling. Grease or dirt caked on the outside of the motor frames can be removed by scraping with flat knives, while loose dirt is

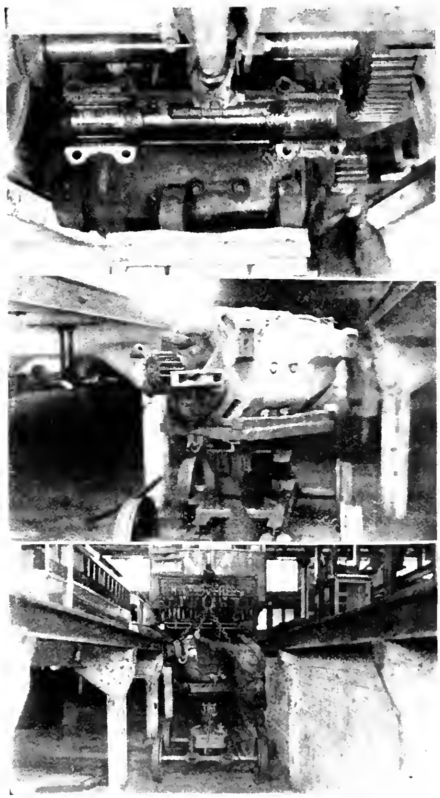

FIG. 4—THREE STEPS IN THE REMOVAL OF A BOX FRAME MOTOR WITHOUT HOISTING THE CAR OR REMOVING THE TRUCK

blown away by compressed air. By placing the motor in a sheet steel tank which is connected to a vacuum-cleaning system, while using the air hose, as shown in Fig. 7, all loose dirt is carried away, the motor is cleaned better and the shop is kept free from dust.

Before overhauling a motor or changing its bearings, the pinion must be removed. The pinion is held in place by a nut, which must first be backed off. To do this the armature is locked by means of a large pipe wrench over the pinion, as shown in Fig. 8, and the nut is then forced off by means of a special four-pronged

spanner wrench. In addition to being keyed and held in position by the pinion nut, the pinions when first placed on the armature shafts are driven very tightly on the taper fit. This is accomplished by holding an annealed pinion against the new one, which is then driven home on the taper by means of a heavy sledge. Some operating companies first heat the pinion in boiling water before driving it on the shaft, thus getting a certain shrink fit, in addition to the driving fit, which insures a good tight pinion. When a pinon is to be removed it requires some special tools to start it off the taper fit. After the nut has been backed off, one method is to use a pronged-shaped wedge that is driven between the back of the pinion and the motor housing. This method tends to damage the armature-bearing collar and the motor housing, and has been replaced by the more mod-

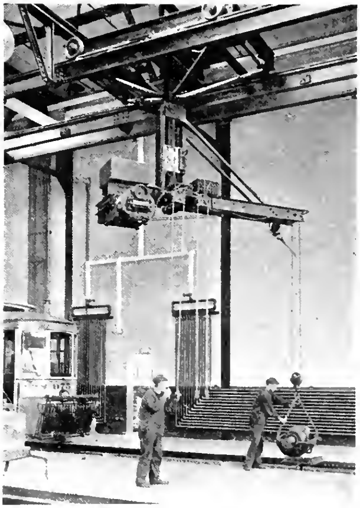

FIG. 5—REMOVING MOTORS FROM PIT JACK BY OVERHEAD CRANE

ern pinion puller shown in Fig. 8. This puller consists of a large forging hollowed out to slip over the pinion; at the open end and on the inner edge of this forging are a number of teeth one-half inch long, corresponding to the number of teeth on the pinion to be pulled. In the closed end of this forging is a heavy jack screw, which is forced against the end of the armature shaft. When a pinion is to be removed the toothed end of the forging is slipped over the pinion, the teeth of the puller meshing with the teeth of the pinion, with a small clearance. When pushed back in place the forging is turned a distance equal to one-half of the circular pitch of the pinion so that the teeth of the forging line up with the teeth on the pinion. The jack screw is then forced against the end of the shaft and pressure is exerted on the pinion teeth from the rear, which forces off the pinion. This scheme has the advantage of forcing off the pinion without doing any damage to the motor housing or bearings.

Removing the Armature from a Box Frame Motor—To remove the armature of a box-type motor from the frame special tools are required, as shown in Fig. 9. The hand method requires one short and one long piece of pipe, bent for convenience, and having pivoted on one end two rings that fit over the ends of armature shaft. Both housings are removed and the rings on the long

FIG. 9—HAND ARMATURE TRUCK

piece of pipe are slipped over the commutator end of the shaft, while the rings of the short piece of pipe are slipped over the pinion end of the shaft. Two men on the outer end of each piece of pipe lift the armature, slide it out through the pinion end of the frame and let it down on a grooved block. The rings on the ends of the pipes are then slipped from the shaft, and the armature can be picked up by the overhead crane.

By the machine method damage to the brushholder and motor windings is less likely to occur. Also, as is readily seen in Fig. 10, it is not necessary to remove the commutator end housing. The pinion end housing is

FIG. 7—VACUUM BOX FOR CLEANING MOTORS
Covers temporarily removed to show motor in position.

removed and the motor is set on the carriage; the special lathe centers are entered in the armature shaft and locked, thus supporting the armature. The carriage is then shifted in the direction of the commutator end of the frame, the long lathe center going through the commutator end bearing opening. In this manner the frame

is shifted far enough to clear the armature, when the latter can be hoisted out of place by an overhead crane.

Removing Armature Bearings—To remove worn and defective bearings, and also to force re-babbitted

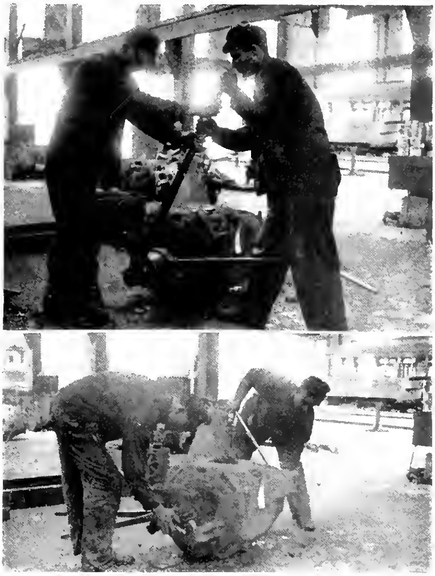

FIG. 8—METHOD OF REMOVING PINION NUT (BELOW) AND PINION (ABOVE)

and new bearing shells into place, a motor-driven press is used. This operation requires from three to five tons pressure, which is necessary in order to prevent the

FIG. 9—VACUUM BOX FOR CLEANING ARMATURE CORES

bearings from becoming loose in the housings. Loose bearing shells should not be used, as they will soon strip the key or dowel pin and turn in the housing, thus interfering with the oiling system. If a loose shell must be used it should be shimmed; i. e., a thin shell or strip of sheet iron should be first placed around it and then both forced into the housing.

ARMATURE ROOM

The armature room, which is located in one end of the motor shop, is equipped for completely repairing all motor parts. When first received in the armature room, if only a few coils are to be removed the armature is thoroughly blown out to remove all loose particles of dirt. If the armature is to be entirely rewound it is not blown out until after all of the old coils have been removed from the core. This cleansing operation is done with a compressed air hose, the armature being placed

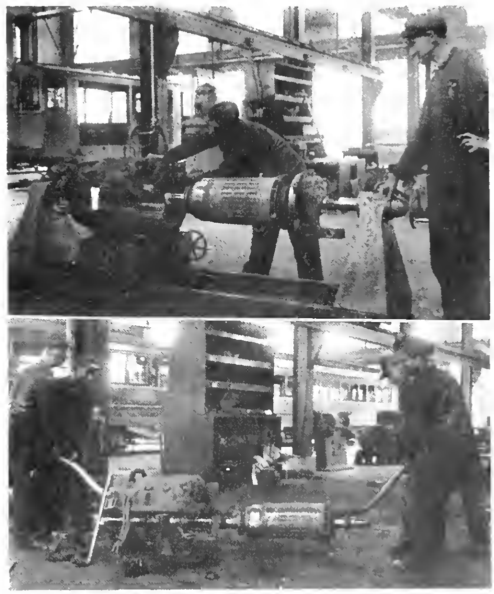

FIG. 10—MACHINE AND HAND METHODS OF REMOVING ARMATURE FROM A BOX FRAME MOTOR

in a sheet steel case connected to the vacuum system, which carries away all the dirt and dust, as shown in Fig. 9.

After the armature core has been thoroughly cleaned out the slots are re-insulated with fish paper cells which have been rubbed with paraffine to make the coils slide in place easily, the coils are placed in the slots and driven home with a soft hammer or with a piece of fiber placed over the coil. If it is found that the coils are not tight in the slots additional strips of insulating material, such as fuller board or fish paper, should be placed at the side of the slots between the laminated iron and the paper cells. If the coils do not fill the slots so completely that the top coil extends about one thirty-second of an inch above the top of the core slot, filling pieces of fuller board and fish paper are placed between the top and bottom coils to build the coils up to this height. This is necessary in order that the band wires shall pull

down on the coils rather than on the core, thereby preventing vibration of the coils. The commutator and the individual coils are then tested for grounds and short-circuits by a lighting-out set, as shown in Fig. 12. Before the leads of the coils are connected into the slots of the commutator both the slots and leads are brushed with a non-acid flux (rosin dissolved in alcohol).

After the armature is rewound and the leads have been inserted into the commutator necks, these connections are again brushed with a non-acid flux. The commutator neck is heated, where soldering is to be done, by a large iron that is kept hot continuously by means of an air and gas connection, as shown in Fig. 13. Half and half solder is used. Some manufacturers and a few large operating companies use pure tin solder for this work, which is more difficult to handle, but gives better results in service, as the melting point of pure tin is about 30 per cent above that of half and half solder.

A very important factor in connection with this work is to have the iron well tinned. This is done by filing

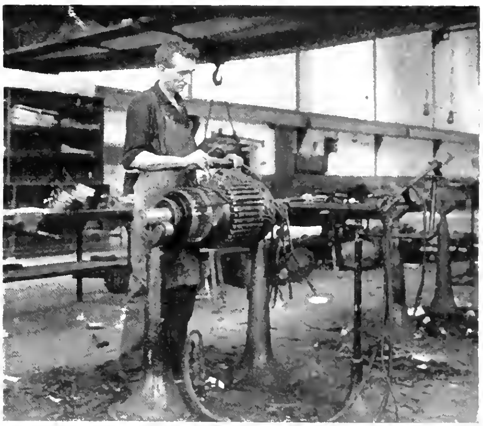

FIG. 11—REWINDING AN ARMATURE

the surface and dipping it while hot in a tinning solution of zinc chloride, made by dissolving zinc in muriatic acid.

Commutators which have been repaired are tested for grounds and short-circuits by the lighting-out circuit, shown in Fig. 12, before they are replaced on the armature spider or shaft. After they have been replaced and before the leads are placed in the commutator necks they are again tested, and they are also tested after the leads have been connected to the commutator and before soldering.

Banding Armatures—After being soldered the armature is banded, as shown in Fig. 14. The lathe is driven by an adjustable-speed motor, thus getting a wide range of speed for banding. The banding wire, which is a high-grade steel piano wire, No. 16 gauge, is carried on a reel on the same carriage that holds the tension adjuster. The wire from the reel is run through the tension adjuster, which consists of a number of small wheels or pulleys held between two adjustable plates which regulate the pressure on the pulleys. The pressure used in banding is approximately 400 pounds and is under the control of the bander.

Strips of tin or copper about three-eighths inch wide and approximately 0.02 inch thick are placed under each

FIG. 12—TESTING A COMMUTATOR AND A REWOUND ARMATURE WITH A LIGHTING-OUT CIRCUIT

This consists of a lamp across a 110 volt line, with a pair of hand terminals in the circuit. If parts of the apparatus on which the separate terminals are placed are electrically connected the lamp lights up.

band about two inches apart and used as clips to hold the band together. Under the core bands it is advisable to run a strip of tin circumferentially. This strip of tin replaces the strip of insulation usually put under the bands, as experience has shown that this strip of insulation is liable to dry out in service and allow the bands to become loose.

After all bands are in place they are soldered, using preferably a pure tin solder. It is very important to

FIG. 13—SOLDERING THE ARMATURE LEADS INTO THE COMMUTATOR

keep the bands on the armatures tight, and if any of the bands of an armature show signs of being loose all old bands should be removed and the armature entirely rebanded. This is good practice from a safety-first standpoint, as loose bands mean loose coils, thus allowing movement of coils in the slots, which rapidly wears

away the insulation and results in premature grounds and short-circuits.

Slotting the Commutator—After being banded, the armatures are carried to a special lathe located in the armature room convenient to the banding lathe, Fig. 15. This lathe is fitted with a motor-driven saw that cuts

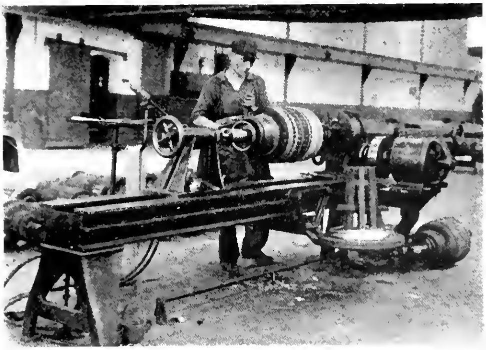

FIG. 14—BANDING THE ARMATURE

the mica three sixty-fourths of an inch below the surface of the commutator. As it is important that all of the mica be cut away between the segments by this operation, this saw should be about 0.010 inch wider than the thickness of the mica. If the saw does not cut away all of the mica it becomes necessary to clear the grooves of all remaining particles of mica by means of a small hand saw, made from a piece of hack saw blade about five inches long set in a block of wood. A clean slotted commutator is essential to prevent low bars and flat spots. It lengthens the life of the commutator and greatly improves commutation.

Armature Testing—Completed armatures are removed to a special table in the test room adjacent to the

FIG. 15—SLOTTING THE COMMUTATOR

armature room. This table has mounted on it a support for the armature and a pair of carbons which are pressed by springs against the commutator 90 degrees apart, regardless of the size of the commutator. Alternating current from a 110 volt, 60 cycle circuit is passed through the armature from these brushes. The winding is then explored one coil at a time by holding the hand terminals of a voltmeter on adjacent commutator bars, as shown in Fig. 16. The movement of the voltmeter needle indicates the condition of the coil connected to the commutator bars on which the exploring terminals are placed. If the coil is in good condition a certain deflection is obtained, depending upon the number of turns in the coil. An excessive voltage indicates that the coil circuit is open. If no voltage is indicated, the coil is short-circuited, while a reversed reading indicates a reversed connection of the coils.

An armature which has passed the test table is then tested for insulation to ground by placing one terminal of a test box on the shaft and the other on the commutator, as shown in Fig. 16. This test box has two

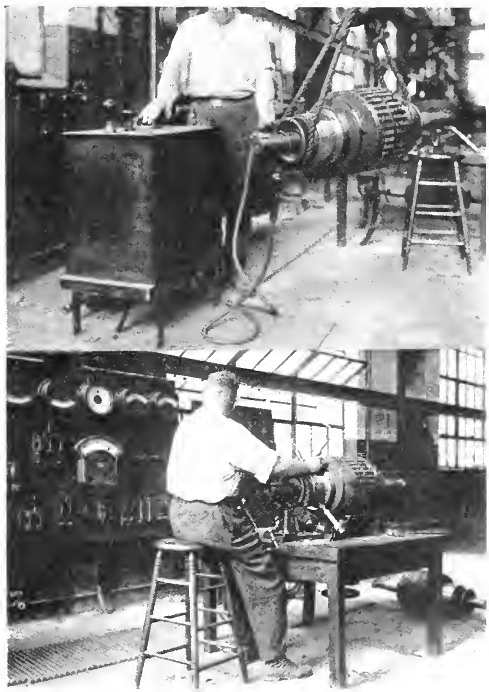

FIG. 16—TESTING THE REWOUND ARMATURE FOR GROUNDS, SHORT-CIRCUITS AND OPEN CIRCUITS

dials, one giving a total voltage of 2000 volts in steps of 200, and the second having a total of 4000 volts in steps of 200, so that there is available a maximum of 6000 volts. A standard test of 1600 volts for one minute is given on 600 volt armatures that have been entirely rewound with new coils. An old armature which has been repaired by replacing a few coils is tested with 1200 volts for one minute.

Field Coils also are repaired in the armature room. The damaged insulation is cut away from the coils and new insulation of treated linen tape, with a protective winding of cotton tape, is wrapped on the coil, as shown in Fig. 17. After the repairs are completed the coil is

placed over the poles of a special testing transformer, as shown in Fig. 17, and alternating current is passed through the primary coil mounted under the table. The ends of the coil being tested are left open, and if the coil is in good condition a certain definite reading is obtained on a wattmeter connected in the primary circuit. If the wattmeter reading is materially greater than this normal reading, the coil being tested is short-circuited. To test for an open circuit, the ends of the coil are fastened together. An increased reading of the wattmeter, depending in amount on the number of turns and size of wire in the coil being tested, indicates that a complete circuit exists through the coil. If there is no increase in the wattmeter reading the coil circuit is open.

Dipping and Baking—In the armature room is located the dipping and baking room, Fig. 18, enclosed in tile walls. Here repaired or rewound field and armature coils, and also completely wound armatures, are

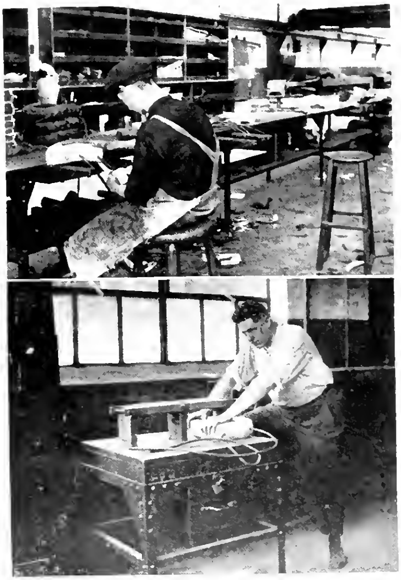

FIG. 17—REPAIRING AND TESTING A FIELD COIL

dipped in an insulating and heat-resisting varnish, after which they are baked by steam heat at a temperature of approximately 120 degrees C. This treatment is a big factor in insuring these parts against breakdowns and grounds due to moisture or lightning, and practically doubles the average life of the parts in service. Impregnating the completed armatures also tends to prevent breakage from vibration. After an armature has been thus impregnated it is more difficult to repair but, on the other hand, is much more liable not to need repairing.

TRUCK SHOP

The truck shop is located opposite the motor shop and all repairs on trucks are made in this department. Cars sent in for repairs are usually sent to this shop first. The car body is lifted clear of the trucks by an electric crane, as shown in Fig. 1, and the trucks run out. If no part of the truck requires repairing except the wheels or axles, the wheels may be changed without removing the truck or lifting the car body, by using a special wheel pit jack. As shown in Fig. 19, a section of the track carrying the

FIG. 18—THE DIPPING AND BAKING ROOMS

wheels is let down to the pit floor level and the wheels are rolled out of place on the pit track. This jack is pneumatically operated by means of levers located on the floor of the pit. New wheels and axles are then put in place in the same manner. The pits have special receding supporting posts arranged so that they will not interfere with the passage of wheels on axles on the pit tracks.

ERECTING SHOP

The erecting shop is the largest building in the group and is divided into three rooms, one for taking care of

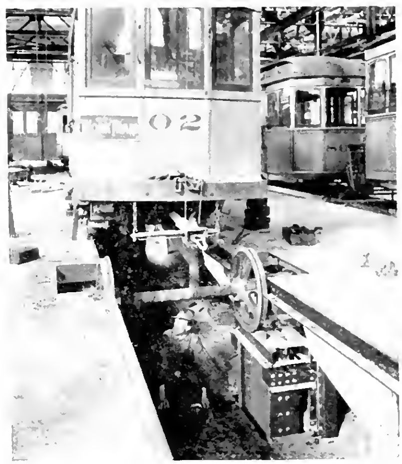

FIG. 19—WHEEL PIT JACK
For removing wheels from truck without lifting car body.

light body repairs which cannot be done at the operating stations, one for general overhauling purposes, and the third housing the machine shop. The light repair section contains six tracks spaced 16 feet from center to

center, two of them being constructed with inspection and repair pits extending the full length of the building. The erecting shop proper contains seven tracks extending through the building, all of the tracks in both departments being served by the transfer table. Six of these tracks are set on 16 foot centers, and the seventh passes through the center of a 51 foot aisle, which has been set aside for the storage, cleaning and repairing of sashes, doors and seats. Enclosed in brick partition walls at one end of this space is the varnish remover room. The floors in the general overhauling sections of the shop are of concrete, with a sidewalk finish of cement, while those in the storage and repair departments are of creosoted wood block, which was employed

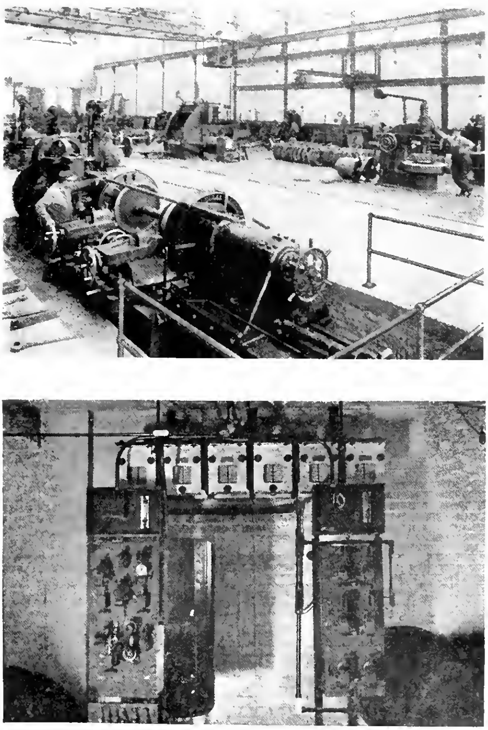

FIG. 20—A 42 INCH WHEEL LATHE

Driven by a 40 hp, 525-1050 r.p.m. commutating-pole motor, with a 7.5 hp, 1150 r.p.m. motor for the feed. Its operation is controlled by a pushbutton station on the machine, the automatic starting panel being in the basement.

because a resilient floor was desired and because asphaltum would not stand up under the rough usage common to this kind of work.

The Machine Shop is completely equipped to take care of all machine work which is necessary in the repair of cars and the construction of new types. A single track passes down the center of this shop from the transfer table. On the main floor all the heavy machine work on car parts is done, commutators, trolley wheels, car wheels and axles are turned, car wheels are pressed on and off and axles are straightened. The heavy machine tools, embracing the wheel lathes, presses, milling machines and boring mills occupy space on each side of the single track entering the shop. The machine tools for handling the lighter work are located in a 15.5 foot wide balcony, which occupies one side and end of the machine shop.

The machine shop illustrates specifically the type of motor drive which is common throughout the entire Harvard shops, viz., the motors are mounted either on or adjacent to the driven machine, and complete automatic control panels, which are operated entirely from push buttons located on the machines convenient to the operators, are located in the cellar below, as shown in Figs. 20 and 21. In this way maximum convenience is secured for the operator and no valuable floor space is taken up by this apparatus. The installation of a complete motor-driven shop was found very advantageous, in that each machine is rendered independent and can

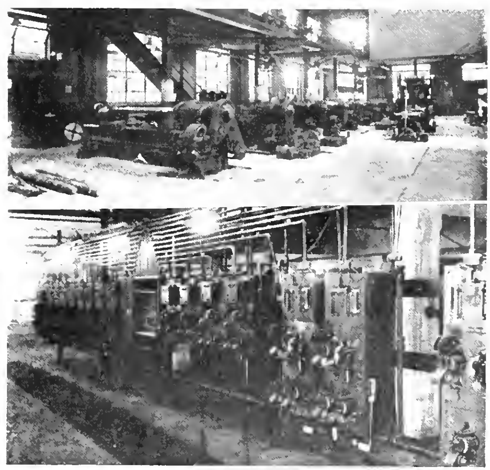

FIG. 21—A ROW OF ENGINE LATHES IN THE MACHINE SHOP

The controllers for these lathes are mounted beneath them in the basement and are operated by pushbuttons on the respective machines.

be placed wherever desired. In general, this means that the machines can be so located that materials and work can pass through the shop with less time and handling; floor space can be used to the best advantage; and trouble at one machine does not necessitate shutting down any others. The automatic control and pushbutton system affords a considerable saving of time and labor to the operator; and a greatly increased speed range, as compared with the limited number of steps obtainable by change-speed gears, means that each machine can be pushed to the economical limit of the particular job, instead of having to work at the next lower limit as determined by the gear ratios.

In one corner of the machine shop is located the wheel and axle department, where the wheels are overhauled before being sent to the truck department

Two wheel presses are provided, one for removing wheels and gears, Fig. 22, while the other is used to push on new or turned wheels. The wheels and gears are pressed on under 40 tons pressure, while approximately 60 tons are required to remove them. No keys are used, as the friction produced by the heavy pressure

FIG. 22—MACHINE FOR PRESSING CAR WHEELS OFF OR ONTO THE AXLES

is depended upon to hold the wheels secure. A vertical boring mill is used to turn the gear and wheel centers to the proper dimensions, 0.006 inch being allowed for press fit.

Wheels which are worn too far to be operated safely are turned down on a wheel lathe, as shown in Fig. 20. This lathe is placed in a pit so that the wheels can be rolled from the floor into the lathe and the work set up without the use of a crane. These worn wheels are not reduced to any standard diameter, but are machined in pairs to as large a diameter as possible, depending upon the metal which must be removed to true up the tread and to get the proper flange shape. A new wheel of the roll-steel type will be reduced about one and three-eighths inches on a side, or a total of two and three-fourths inches in diameter, before being condemned to

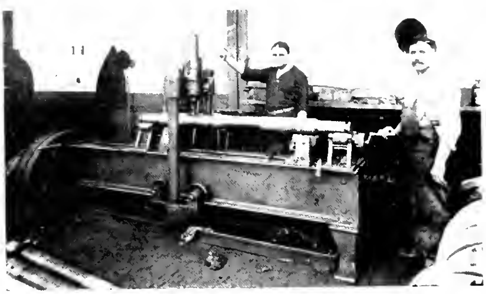

FIG. 23—AXLE STRAIGHTENER

the scrap heap. This allows an average of three turnings, and the wheels will average about 90 000 miles service.

After the gears and wheels have been pressed off, the car axles are tested to determine if they are straight by being placed on two sets of rollers and then revolved by a crank geared to one of the sets. While the axle is being rotated by one workman a piece of chalk is lightly held against it at the journal. If any deflection is noticed, pressure is applied to the high side of the axle by a plunger operated by a jack, which is mounted on a carriage traveling along the length of the axle, as shown in Fig. 23. In this manner both ends of the axle are tested and made to run true before being put back in service.

In addition to being used for the control panels, the basement serves as a convenient storage for car wheels and for lathe turnings, which are thereby protected from the weather. They are handled by means of the overhead crane through a trap door in the floor.

Car Straightener—With the extensive use of steel cars came the problem of keeping them in proper shape and alignment, since they are always exposed to collisions from other cars and vehicle traffic. At the Harvard shops is found a very clever device, known as a car straightener, Fig. 24. A steel car that has been thrown out of alignment is placed in this device and by means of jacks placed at desired points is brought back into

FIG. 24—CAR STRAIGHTENER

alignment. When not in use the large jaws swing back onto the shop floor out of the way.

FORGE SHOP

The forge shop is equipped to do all the blacksmith and forge work required in the maintenance of cars and the manufacture of new ones, such as heavy forgings, repairing fenders, bending pipes and car shapes, including arc-welding repairs and babbitting bearings. Among the interesting equipment is a motor-driven bulldozer equipped with a special device for bending pipe and rods. This device was designed by the foreman, who claims that enough pipe can be bent in one day for the airbrake equipment of 50 cars.

Another interesting application is the motor-driven 800 pound power hammer shown in Fig. 25. Among other tools, this hammer is equipped with a special form for truing up bumper irons for cars, which often get badly bent in wrecks. The iron is heated and is quickly hammered into proper shape between the two parts of this form in the hammer.

Arc Welding—In one corner of the forge shop is located the arc welding department, separated from the main room by a partition wall about eight feet high; one end is left open and is separated from the main room by an asbestos curtain mounted on a large roller. In this room repairs are made on truck frames, motor cases and housings, gear cases and various detail parts of the equipment by both the carbon electrode and metal electrode methods.*

Dipping Fenders—The painting of fenders, which usually requires considerable time to accomplish with a brush or a spray pot, is economically and thoroughly accomplished by a dipping outfit. This outfit is located in one corner of the forge shop handy to where the fenders are reconstructed. When ready for final painting the fenders are placed on hooks suspended from an air hoist over a tank set in the ground. This tank is

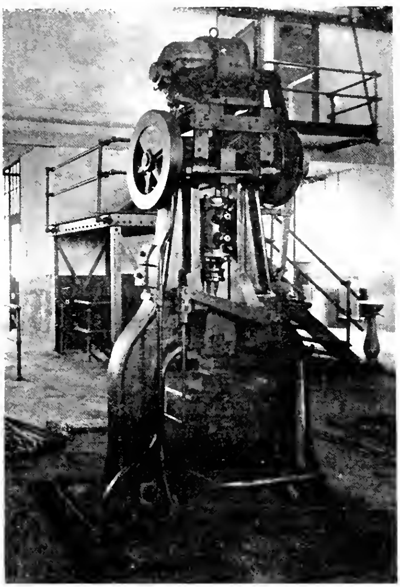

FIG. 25—AN 800 POUND ELECTRICALLY-DRIVEN POWER HAMMER

arranged to receive an entire fender, and contains water with about six inches of black paint on the top. The fenders are then dipped in the tank by means of the air hoist and hung on a carriage mounted on an overhead rail that will hold five fenders. After the excess paint has drained off the dipped fenders the carriage with its five fenders is pushed along the overhead rail into an enclosed drying compartment, where they are air dried for at least six hours.

The Bearing Department, where all bearings are rebabbitted, is located in one corner of the forge shop, separated from the main room by a brick wall about eight feet high. One metal—a high-grade tin base alloy—is used in pouring all bearings. Old bearings sent into this department to be recast are taken as they are received, covered with oil and grease, and placed in one of the melting pots used exclusively for this work. When the old metal is burned off of the old shells they are removed from the pot, cleaned off and set aside to cool, after which they are ready to be babbitted. The

FIG. 26—A CORNER OF THE BABBITTING ROOM

reclaimed metal from the old bearings is then poured into pigs, which are remelted with the bars of new metal for rebabbitting shells.

Metal moulds are used in connection with rebabbitting of the bearing shells, a set of moulds being available for all different types of shells. The mandrels for making the journal fit are given a slight taper, so that they can be forced out readily when the metal has hardened.

The pots from which the metal is poured are heated by a gas flame. The temperature of the metal is determined by the judgment of the workmen, who by experi-

FIG. 27—A GENERAL VIEW OF THE PAINT SHOP
Showing adjustable scaffolding for painting cars

ence in noting the flow and structure of the metal as it congeals know whether its temperature is just right. Some manufacturers use a thermocouple to regulate the temperature of the metal, which is considered more reliable and will more likely tend to produce uniform results in the rebabbitted bearings. The metal is poured through

*See articles by Mr. E. S. Zuck on "Arc Welding" in the JOURNAL for January, 1914, p. 37, and October, 1914, p. 565.

a long spout that takes it from under the top of the fluid metal, thus always insuring clean babbitt, free from the oxides and dirt that form on the top of the molten alloy. For convenience in handling, the pot is hinged and travels on an overhead trolley rail so that it can be pulled out from under the gas flame to where the mould has

FIG. 28—THE PAINT MIXING ROOM

been assembled ready to receive the hot metal, as shown in Fig. 26. The pot is then tilted forward by means of the handle until the hot metal runs out of the spout into the mould, and the door at the front of the gas flame is raised by means of a foot lever located under the bench, so that the gas flame and pot are protected from surrounding air currents.

After being poured the bearing is slid along on the metal bench under an air-operated plunger that pushes out the mandrel. The mould is then knocked down and the rebabbitted shell taken to a finisher, who trims off the ragged edges from the bearings, after which the bearings are put in stock ready to be requisitioned by the motor department.

PAINT SHOP

The paint shop is divided into three sections, two for use in painting cars and a third for washing the cars. Six tracks on 16 foot centers pass through each of the two paint shop sections and two through the washroom. The paint shop proper is arranged something like the erecting shop, having an area embracing six tracks on each side of a 50 foot aisle, where miscellaneous parts, such as signs and sashes, are cleaned and painted. One end of this aisle is occupied by a paint-mixing room, shown in Fig. 28, which is enclosed in brick firewalls, and there is also a small storeroom and office at the end. Concrete floors have been provided throughout the paint shop, and these, like the firewall and metal-clad doors between the two paint shop sections, effect a reduction in the insurance rate. Although the buildings are built exclusively of concrete, steel and brick, sprinkler systems are provided in all the shop buildings.

In the paint shop there are two window-washing machines. These are rectangular in section and are provided with a pivoted wooden platform in the center. Sashes and also car signs are laid on this platform, and a goose-neck shower fixture, extending from a pipe connection, serves to spray hot water over them. As sashes are taken from each car they are kept in steel racks, so that when they are to be replaced no trouble is experienced due to getting them in the wrong car.

In the washroom, which is essentially a part of the paint shop, is located a machine for scrubbing car seats, Fig. 29. The rattan seats and backs are removed from the car and placed on this machine against revolving brushes where, with the assistance of a good supply of water, the seats are cleaned.

WOOD-WORKING SHOP

The wood-working shop is divided into a mill room and a cabinet shop, a small tool room enclosed in a sheet steel and wire mesh partition occupying one corner of the mill room. A gallery extending approximately the full width of the mill room serves for the employees' locker room and lunch room. One end of this gallery is occupied by the templet room, and adjoining it is the space provided for the indirect radiation auxiliary heating system.

A single track enters the wood-working shop from the transfer table beside it. The center of this track is parallel to the mill-room partition separating it from the cabinet shop. A 32 foot aisle between this track and the building wall is used for storage of lumber.

The equipment in the cabinet shop consists principally of benches and facilities for gluing and finishing cabinet work. By separating the cabinet from the mill room, it is kept free from the dust and dirt incidental to the use of wood-working machinery.

All wood-working machine tools are driven by motors in the basement below the mill room, where also are installed the conduit carrying the power circuits to the various tools, the main and return pipes in the heating system and the shaving and refuse exhaust system.

FIG. 29—SEAT WASHER

To minimize accidents the management has, wherever possible, covered all moving parts, such as gears, pinions, pulleys, belts, etc., with either sheet iron or wooden housings. Since it is not advisable to box in motors on account of overheating them, also to economize space and to obtain a more efficient drive, the

motors in most cases have been mounted on concrete pillars in the basement, and beside each motor is placed its automatic control panel. This location of motors eliminates all line shafting. To start a machine the workman merely presses a button. To stop it he presses another button.

In the basement is also installed a blower belted to a 40 horse-power, 550 r.p.m. motor. Pipes from this blower extend to the saws, planers, mortising machines and all other wood-working machines on the floor above. Also pipes extend to numerous floor sweeps, or holes in the floor, located near the various machines and work benches. To clean away the shavings and sawdust from the floor near his machine or workbench, the workman merely has to remove a cover from one of these floor-sweeps and shovel the shavings and refuse into it. All this refuse is drawn into the boiler room, where it is fed into one of the boilers. The refuse is sufficient to heat all of the hot water and steam needed during the summer months. The larger pieces of refuse wood are turned into rounds and handles when possible, while pieces not suitable for this are cut up on a 36 inch band saw and stored away in the basement for use in starting fires in cars during the winter months.

For the heating of this building a hot-air blower belted to a 7.5 horse-power, 1850 r.p.m. motor is installed. This draws fresh air from the outside over steam-heated grates and forces it into the room. This system distributes heat uniformly and creates a good circulation of air currents throughout the room. During the hot months the steam can be shut off and the same system used to cool the building.

Some Points on Car Wiring

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Westinghouse Electric & Mfg. Company

The wiring of a car with control and power circuits is a feature of the equipment that necessitates careful consideration, as it is a factor on which the reliability of car operation will greatly depend. Of course, permanence of insulation is one of the fundamentals on which the success or failure of any equipment depends. A failure in service usually reflects on the manufacturer of the electrical equipment, whether it was due to a short-circuit or a ground in the wiring or to some piece of the apparatus. Therefore it is essential for the installing engineer to keep this in mind and make a study of the details of car wiring and see that the best types of construction are carried out, thus minimizing this possibility of failure.

After the motors, the control is one of the most important parts of a car since, for successful operation, the switches must be closed and opened according to some predetermined sequence. It must stand all weather conditions, shocks and vibrations encountered in rough service.

HANGING THE APPARATUS

The control apparatus, air cylinders and brake rigging should be placed so that the weight is approximately evenly distributed on the two sides of the car. Consider, for example, two pieces of apparatus weighing 100 and 200 pounds, respectively. If the one weighing 100 pounds is placed two feet from the center line of the car then the other should be placed one foot from the center line on the opposite side. The sum of all these moments should be within 8 or 10 percent of each other, otherwise the car body will have a tendency to incline to the heavier side after being placed in service.

Accessibility and future maintenance should be considered rather than the saving of a few feet of cable in the initial installation. In Fig. 1 is shown the mounting of a switch group, line switch control resistor and control change-over where accessibility was considered as a primary feature. The main resistors are mounted on the left near the edge of the car.

Space is an important factor under a car, and any arrangement will have its disadvantages. Usually the layout of the control and brake apparatus is determined prior to the construction of the car, so it remains only

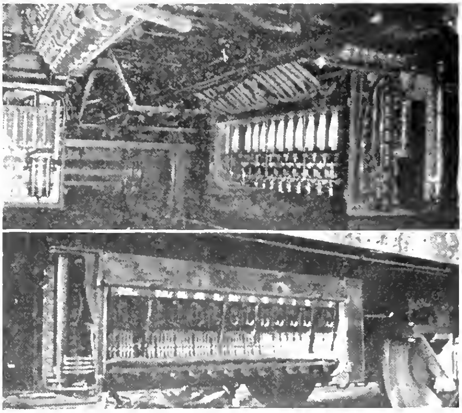


FIG. 1—MOUNTING OF CONTROL APPARATUS UNDER CAR
The switch groups have covers removed.

to place it and install the air piping and conduit for the control and power cables. All short bends should be avoided if possible, because they make it very difficult to pull in the cable. Generally the equipment is installed by the builder. Car builders usually keep experienced

wiremen, pipe fitters and have power-operated pipe-cutting and threading machinery, etc., and are better prepared for such work than the railway companies.

WIRING OF CONTROL CIRCUITS

It is very important that the control circuits be installed permanently. Otherwise they may prove to be a source of trouble. There are two primary requirements to keep in mind while installing these circuits:—

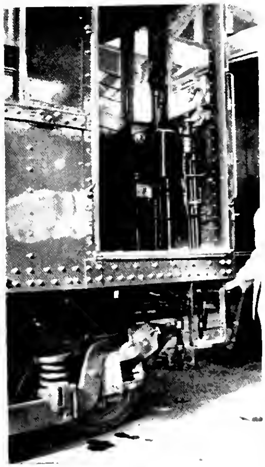


FIG. 2—MOTORMAN'S COMPARTMENT
Showing master controller and control and reset switches.

a—Use flexible wire only, so that vibration with the motion of the car will not break it.

b—Use wire with a good insulation and with sufficient mechanical strength.

Where a number of cables enter a piece of apparatus, they should, if possible, be arranged so that any one can be withdrawn without disturbing the others. Where a control change-over switch or third junction box is employed, practically all of the control cable will connect through it, and if a mass of control wires are taped together it would be very difficult to withdraw any one should it become damaged. Splicing should be avoided where possible. Where a small stranded wire becomes filled with solder it becomes inflexible and is easily broken at that point.

When a tap wire is to be taken off it should not leave the main wire at the point where the splice is made as shown at *B*, Fig. 3, but should be taped along with it for about an inch, as shown at *A*, and then taken off in the direction required. This will leave the tap wire flexible at the point *C* where it leaves the main wire and reduce the possibility of its being broken, and will also insure better insulating at the splice.

A control cable should not be connected so that any of the individual wires are in tension. Too much slack must also be avoided, as the wires may vibrate with the motion of the car and cause the insulation to chafe, finally resulting in a short-circuit or ground. All terminals should be numbered or marked with some kind of a tag, as shown at *D*, Fig. 3. This will prove valuable in the future in tracing the wiring.

MAIN CIRCUIT WIRING

Some operators specify that each main circuit cable be run in a separate conduit, while others use several, as the case may require. In the main circuit wiring, shown in Fig. 1, each cable is run in a separate conduit.

When connections are made outside of the switch group the cable should have a **U**-shaped loop before it enters the group, as shown in Fig. 1. The power circuits seldom give any trouble except at the motor leads. If these leads are left long and hanging loose they may catch on some projection of the motor case or truck and cause injury to the insulation when the car passes around a curve. This may result in a short-circuit and possibly an expensive repair bill, as well as a delayed car. These leads should be brought up to the body of the car in some kind of a loop, preferably a **U** shape, leaving just enough slack to allow passing around the sharpest curve. The main circuit cables that connect to the motor leads should extend only a short distance out of the conduit, leaving the more flexible motor lead to take care of the movement of the car body.

The control and power circuit wiring should be given a thorough test before the car is offered for service, to make sure that the switches operate in the proper sequence and that the train-line connections are correct for train operation. A voltage test should also be given to eliminate the possibility of a ground or poorly insulated connection.

ECONOMY OF LABOR

It is recognized that specialization will produce an efficient workman. Where the output and number of cars to be equipped is sufficiently large, great economy can be effected by having workmen for each operation, i. e., for installing the apparatus and for wiring control and power circuits, respectively. Templets that conform to the terminal board of the junction boxes and master controllers may be used to great advantage. A master controller is shown in Fig. 2 where these forms were used. The use of these templets or forms makes it possible to cut the wires to the proper length and solder the terminals on at one end before the cable is pulled into the conduit, as well as to relieve the wireman of some tiresome work in an inconvenient place.

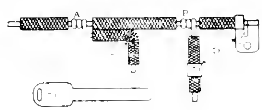


FIG. 3—METHOD OF SPLICING WIRES

Neatness is very essential; work done in a slouchy manner not only has a bad appearance, but is also unreliable. Since the problem of car wiring is of primary importance in securing reliability of service, railway companies and manufacturers can hardly give it too much attention.

Low-Floor Car Control

KARL A. SIMMON

THE increased use of low-floor cars as a means of reducing the unloading and loading time element has necessitated the development of various kinds of apparatus, among the more important of which is the control. A controller box which, together with a master controller, control switch, grid resistor, main fuse and the necessary inter-connecting cables, constitute a complete equipment for this kind of cars, is shown in Figs. 1, 2 and 3. All parts, other than the controller box proper, are of well-known standard design.

KARL A. SIMMON

The controller box is divided into compartments, one containing three switches or circuit breakers, one containing the reverser and commutating switch, and two small end compartments housing the motor cutout switches, relays and control terminals. The distribution of the various elements is such that the working or wearing parts can readily be inspected.

The outline dimensions of the controller box are shown in Fig. 4. The arrangement of the compartments and the method of mounting is such that this piece of apparatus can be hung either longitudinally or transversely with respect to the car framing. While the maximum depth is over seventeen inches, this occurs only above the switch compartment, the top of which is

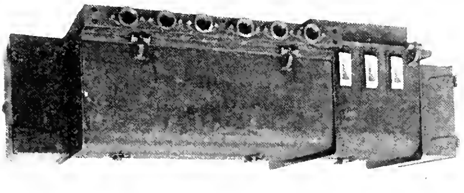
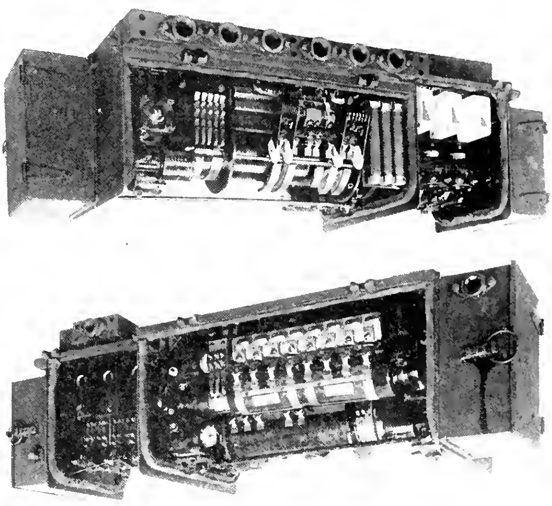


FIG. 1—HLD CONTROLLER BOX

only fourteen inches square and extends between the sills, so that the effective depth of equipment beneath the car sills is only fourteen and one-half inches.

Each of the three unit switches is of the well-known HL or electropneumatically-operated type, the various elements being interchangeable, readily accessible and simple in construction, as is shown in Fig. 4. The reverser is pneumatically operated, rugged and comparatively large for the work to be done, the reduction in depth to meet low-floor conditions not being a material handicap to liberal design when pneumatic power is available.

The commutating switch, which cuts in and out resistance according to a predetermined sequence, is located adjacent to the reverser. This switch is of the drum type, operated by the well-known PK or balanced air pressure method, which has been employed so successfully in both city and subway service. The auxiliary details located in the small end compartments, such as relays and cutout switches, are of standard construction, rugged yet light in weight and positive in action.



FIGS. 2 and 3—FRONT AND REAR VIEWS OF HLD CONTROLLER BOX, WITH COVER REMOVED

The main circuit connections for a typical two-motor equipment are shown schematically in Fig. 6. This diagram shows in detail the distribution of the three unit switches or circuit breakers which open and close the circuit during normal operation as well as during overloads and, in addition, effect the transition from series to parallel. All main circuit changes not effected by the unit switches are made on the commutating switch drum which, owing to the inherent arrangement of connections, does not interrupt the circuit during normal oper-

ation. The resistance changes effected by the drum provide an especially smooth acceleration with four notches in series and parallel. Shunting transition is employed when passing from series to parallel, thus making it possible to insert all of the external resistance ahead of the motors.

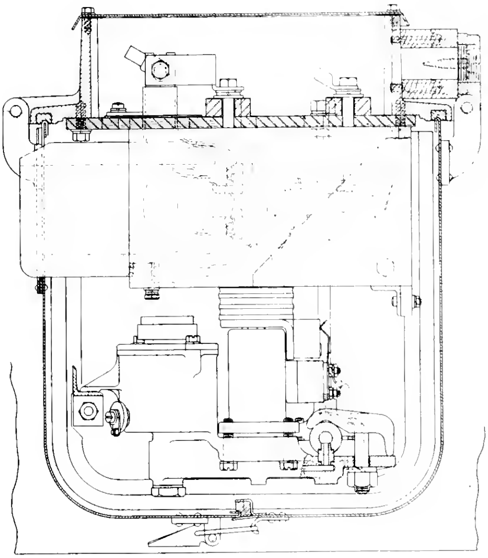


FIG. 4—SECTIONAL VIEW OF SWITCH COMPARTMENT

Type HLD control, while primarily designed for light-weight, low-floor cars, is capable of handling two or four motors having an aggregate capacity of not over 200 hp at 600 volts. The control circuits may be operated from a storage battery or with line current, very little energy being consumed in either case. The many advantages of this new low-floor car control are more or less similar to the characteristics of HL and PK control, among the more important of which are:—

1—Compactness.
2—Reliability.
3—Ease of installation.
4—Light weight.
5—Low maintenance.
6—Safety.
7—Simplicity.

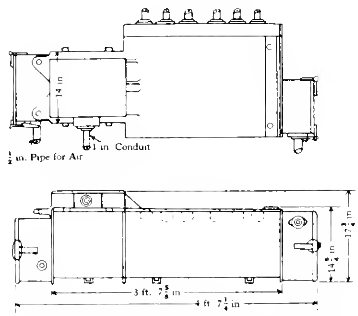


FIG. 5—PLAN AND ELEVATION OF CONTROLLER BOX
Showing outline dimensions.

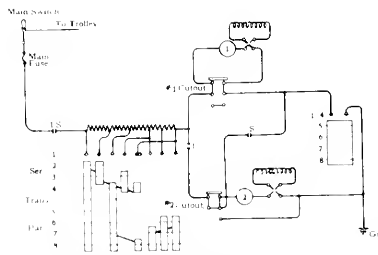


FIG. 6—SCHEMATIC MAIN CIRCUIT DIAGRAM
Two 600 volt motors.

The evolution of city car construction during the last five years appears to indicate the necessity for the adoption by many of the operating companies of this country of a type of control similar to that described.

Light-Weight Grid Resistors

Joseph D. Birrell

SINCE this is the day and age of light-weight car equipments and every part of the equipment comes in for its share of the "cut," it is only logical that attention be given to the reduction in weight of accelerating resistors. This reduction can only be brought about by giving up at least one of the more advantageous characteristics of what is considered a standard grid resistor. This characteristic is "thermal capacity" or heat-absorbing capacity, and when it is considered that, other things being equal, thermal capacity is directly proportional to weight, it will be seen that on reducing the weight the thermal capacity is also reduced in proportion.

When cars operate for long periods in "downtown" service, which is mostly operation on resistor notches, it is a great advantage to have a resistor with large thermal capacity in order that the heat generated may be absorbed by the grids without dangerous temperature rise.

A reduction in grid weight for the same continuous grid capacity can be accomplished by reducing slightly the cross-section of the active resistor element and increasing the spacing of the grids by widening the boss, thus giving better ventilation. The reduction is, of course, accompanied by a reduction in thermal capacity, which amounts to approximately 35 percent average. It will thus be realized that to apply a light-weight re-

sistor more complete and accurate data must be obtained than was formerly the case, in order that the resistor may be "safe" and still the maximum reduction in weight be obtained.

For the sake of comparison, assume two resistors each having the same overall dimensions, ohmic resistance at 25 degrees C. and continuous capacity, but built up as follows:—

(A) STANDARD (NARROW BOSS) GRID RESISTOR	(B) LIGHT-WEIGHT (WIDE BOSS) GRID RESISTOR
One frame of 22—8 in. 3 point cast-iron grids;	One frame of 13—8 in. 3 point cast-iron grids;
Grid pattern A;	Grid pattern B;
Assembled multiple—2, series —11;	Assembled series—13;
Continuous capacity, 109.6 amperes;	Continuous capacity, 109.5 amperes;
Resistance at 25 degrees C., 0.27 ohms;	Resistance at 25 degrees C., 0.265 ohms;
Weight of active material, 72 pounds.	Weight of active material, 52 pounds.

The following is a comparison of a typical frame of light-weight and standard resistors as shown in Fig. 1:—

STANDARD (NARROW BOSS) GRID RESISTOR	LIGHT-WEIGHT (WIDE BOSS) GRID RESISTOR
1—Active material weighs 38.3 percent more than wide boss grid resistor;	*1*—Active material weighs 27.7 percent less than narrow boss grid resistor;
2—Thermal capacity 70 percent (average) more than wide boss grid resistor;	*2*—Thermal capacity 41 percent (average) less than narrow boss grid resistor;
3—Cost of resistor 31.8 percent more than wide boss grid resistor;	*3*—Cost of resistor 24 percent less than narrow boss grid resistor;
4—Standard weight means operating costs as at present.	*4*—Lighter weights tending toward lower operating costs than at present.

Both types of resistors are assembled in the standard manner, i. e., make use of the three-point method of support. The resistors are built up of cast grid units, which are easily replaceable without the risk of other units falling out. The resistor elements have a high melting point, which greatly exceeds the critical temperature or sagging point of either rolled or drawn material.

From Fig. 2 it will be seen that these two particular grids under consideration have approximately the same average thermal capacity per individual grid. The total thermal capacity will therefore, on the average, be in proportion to the number of grids.

Better ventilation and radiation is obtained with the wide boss than with the standard resistor, due to the wider spacing of the grids, as shown in Fig. 1. The amount of air passing through a resistor will, of course, vary with the speed of the car and existing conditions at any particular time under consideration. Due to this better ventilation of the wide boss resistor, the average

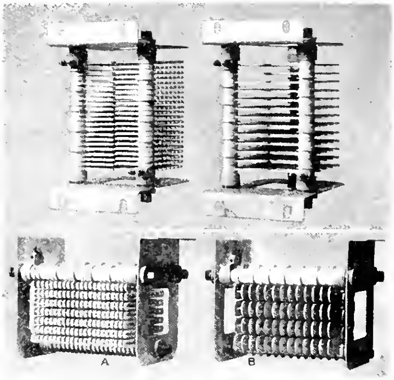


FIG. 1—RESISTORS
A—Standard, narrow boss grid resistor.
B—Light-weight, wide boss grid resistor.

continuous current rating per grid can be materially increased.

Numerous light-weight resistors of the type described are already employed for certain service conditions and are giving entire satisfaction, the reduction in thermal capacity not having reduced the factor of safety

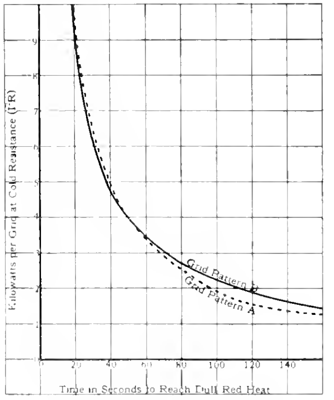


FIG. 2—THERMAL CAPACITY CURVE

sufficiently to affect the reliability appreciably. An application where practically all grades are eliminated and automatic acceleration is used is comparatively ideal for a light-weight resistor.

The Design of Direct-Current Railway Accelerating Resistors

L. J. Hibbard
Railway Engineering Department,
Westinghouse Electric & Mfg. Company

THE design of a direct-current railway accelerating resistor involves three distinct problems:—

1—The determination of the total amount of resistance required in the circuit when the controller is on the first notch.

2—The determination of the number of steps and their ohmic values, into which the resistance must be divided to give uniform acceleration.

3—The determination of the current-carrying capacity of the various steps which is necessary to prevent the overheating of the resistor element.

AMOUNT OF RESISTANCE REQUIRED IN CIRCUIT AT START

The total resistance required in the circuit at start, and the amount of resistance that is cut out at any given

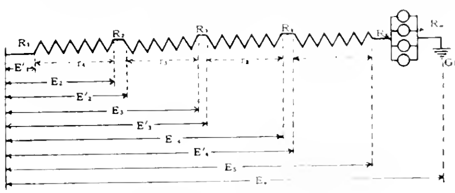


FIG. 1—RESISTOR CONNECTIONS

E_0 = Line voltage.
E_1 = Counter e.m.f. at instant contact is made at R_1.
E'_1 = Counter e.m.f. at instant contact is broken at R_1.
E_2 = Counter e.m.f. at instant contact is made at R_2.
E'_2 = Counter e.m.f. at instant contact is broken at R_2.
E_3 = Counter e.m.f. at instant contact is made at R_3.
E'_3 = Counter e.m.f. at instant contact is broken at R_3.
E_4 = Counter e.m.f. at instant contact is made at R_4.
E'_4 = Counter e.m.f. at instant contact is broken at R_4.
E_5 = Counter e.m.f. at instant contact is made at R_5.

instant, depends upon the permissible rate of acceleration. For car equipments this rate lies between one and two miles per hour per second. To accelerate a car at the rate of 1.5 miles per hour per second it is necessary to exert approximately 150 pounds tractive effort per ton weight of car.

Assuming an acceleration of 1.5 miles per hour per second and given the car weight in tons, it is possible to determine the total tractive effort which must be exerted by the motors. Dividing this total tractive effort by the number of motors on the car gives the tractive effort which must be exerted by each motor. Knowing the gear ratio and wheel diameter, the value of the current which will produce the above tractive effort can be obtained from the torque curve of the motor. Then, by means of the line voltage, the total resistance can be determined. The value of the resistance obtained by this method must be reduced by a factor which varies from 0.7 to 0.8, i. e., the resistance must be multiplied by approximately 0.75 to give the value of resistance which is actually placed in the circuit. The necessity for using this factor is due in general to two causes; first, the inductance of the motors, and second, the regulation of the transmission system. By following the method outlined and by using a constant of 0.75, the amount of resistance which is required in the circuit at start can be determined, and then by subtracting the motor resistance from the total the external resistance which is required is obtained.

NUMBER OF STEPS

To accelerate the motors at a constant rate it is necessary to keep a certain average value of current flowing through them during the acceleration period. When external resistance is used to accelerate a motor equipment the resistance must be cut out in steps of such a value that the current will vary between two limits such that the average value will produce the desired rate of acceleration.

On the average railway equipment the variation in tractive effort should not be greater than 25 or 30 percent. If these values are exceeded the mechanical parts will be subjected to severe strains and the passengers will be jolted unduly.

The number of steps and their ohmic values can be calculated from the following formulae:—*

$$P = \frac{\text{Log}\left[1 - \frac{R_T}{R_m}(1 - CK)\right]}{\text{Log } CK} - 1 \text{ (straight rheostatic notching)}$$

$$\begin{aligned}
r_1 &= C\,K\,R_m \\
r_2 &= C\,K\,r_1 = C^2 K^2 R_m \\
r_3 &= C\,K\,r_2 = C^2 K^2 r_1 = C^3 K^3 R_m \\
r_n &= C\,K\,r_{n-1} = C^2 K^2 r_{n-2} = C^{n-1} K^{n-1} R_m
\end{aligned}$$

Where r_n = First step of resistance cutout.
r_{n-1} = Second step of resistance cutout.
r_{n-2} = Third step of resistance cutout.
And r_1 = Last step of resistance cutout.
R_m = Resistance of motors and wiring.
P = Number of steps.
R_T = Total resistance in circuit at start.
CK = A constant whose value depends upon:—
(1) Motor characteristics.
(2) Variations in torque on each notch. (In ordinary railway service the value of CK will be approximately 1.465, see Fig. 2).

CAPACITY

To determine the current-carrying capacity of each step it is necessary to know:—

*For derivation of these formulae see end of article.

a—The maximum time spent on each notch.

b—$I_{max.}$ and $I_{min.}$ from which it is possible to determine the value of $\sqrt{(I^2_{max.}+I^2_{min.})\div 2}$.

c—The time required to complete one cycle of the speed-time curve. If the time required to complete this cycle varies, the minimum value should be chosen.

Knowing these values, it is possible to determine the root mean square value of the current flowing through each step of the resistor. The resistor element that is used should be able to carry this value of current continuously without overheating. Also this resistor element should have sufficient thermal capacity to withstand the peak loads without dangerous heating. The capacities obtained by this method are safe only on the assumption that the acceleration is automatic. If the equipments are accelerated by hand the above capacities should be increased, the amount of increase depending upon the type of service and upon the class of motormen.

As an example, take an equipment as follows:—

Number of motors	4	
Horse-power of motors	140	
Hourly rating	200	amperes.
Continuous rating	125	amperes.
Resistance of the four motors in parallel	0.045	ohms.
Average line voltage	530	volts.
Gear ratio	21:56	
Wheel diameter	33	inches.
Desired rate of acceleration	1.5	m.p.h.p.s.
Pounds tractive effort per ton weight of car	150	pounds
Car weight	35.8	tons
Type of acceleration		Hand

To find the total resistance required in the circuit:—

Total tractive effort required $=35.8\times 150=5369$ pounds.
Tractive effort per motor $=5369\div 4=1342.5$ pounds.
Torque per motor $=1342.5\times 21\div 56\times 33\div 24=692$ pounds at one foot radius.
Current required per motor (from Fig. 4) = 155 amperes.
Type of notching .... = straight rheostatic.
Average amount of current $=4\times 155=620$ amperes.
Maximum amount of current $=620\times 1.08^*=670$ amperes.
Minimum amount of current $=620\times 0.92^*=570$ amperes.
Inductance and line regulation factor = 0.75.
Resistance required in circuit .... $=530\div 670=0.79$.
Total resistance actually placed in circuit $=0.79\times 0.75=0.595$.

To find the number of steps:—

$CK=1.465$ when the variation in tractive effort = approximate 25 per cent.*

$$\text{Then } P=\frac{\left[1-\frac{0.595}{0.045}(1-1.465)\right]}{Log\ 1.465}-1=4.15$$

Therefore, from the result in last formula four steps are used.

To find the Ohmic value of each step:—

$r_1=1.465\times 0.045=0.0659$
$r_2=(1.465)^2\times 0.045=0.0966$
$r_3=(1.465)^3\times 0.045=0.1415$
$r_4=(1.465)^4\times 0.045=0.2075$

0.5115

Resistance of four motors in parallel ... = 0.0450

R_T for four steps .... = 0.5565
If five steps are used:
$r_5=(1.465)^5\times 0.045=0.3033$

R_T for five steps. = 0.8598

The continuous capacity of resistor which should be selected depends on the length of time it is normally in service. The first grid to be cut out can therefore have a lower continuous capacity than the last one. For average operating conditions, experience indicates that in a four-step resistor satisfactory operation will be secured with the steps having capacities of 30, 45, 60 and 75 percent, respectively, of the total continuous rating of the motors. In the above example the total continuous motor rating is 4×125, or 500 amperes. The continuous rating of the resistors should therefore be

For $r_4=0.30\times 500=150$ amperes.
For $r_3=0.45\times 500=225$ amperes.
For $r_2=0.60\times 500=300$ amperes.
For $r_1=0.75\times 500=375$ amperes.

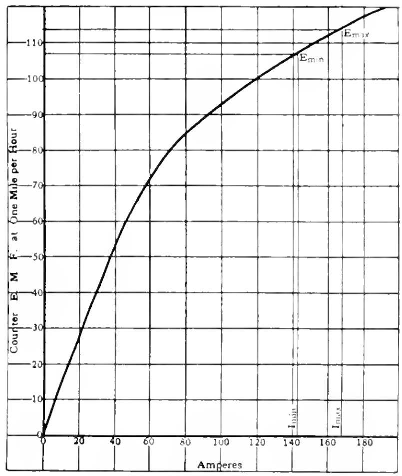


FIG. 2—VARIATION OF COUNTER E.M.F. AND CURRENT

On this curve:—

$$C=\frac{E_{min.}}{E_{max.}}=\frac{106.5}{114}=0.935$$

$$K=\frac{I_{max.}}{I_{min.}}=\frac{167.5}{142.5}=1.175$$

$$CK=0.935\times 1.175=1.1$$

Assuming an inductance factor of 0.75, the value of CK by substitution into formula will be $1.1\div 0.75=1.465$. Also assuming the variation in tractive effort equal to 25 percent. Then for railway motors the tractive effort equals a constant times torque equal approximately a constant $\times I^{1.6}$ or if:—

$$\frac{(\text{Tractive effort})_1}{(\text{Tractive effort})_2}=\frac{I_1^{1.6}}{I_2^{1.6}}=1.25$$

$$\text{Therefore } \frac{I_1}{I_2}=1.1715=\frac{I_{min.}}{I_{max.}}$$

PROOF OF FORMULAE

(Straight Rheostatic Notching)

To derive a formula for the number of steps let

$I_{min.}$ = minimum value of current allowable during acceleration.

$E_{min.}$ = counter e.m.f. of motor at full speed with $I_{min.}$ flowing.

$I_{max.}$ = maximum value of current allowable during acceleration.

$E_{max.}$ = counter e.m.f. of motor at full speed with $I_{max.}$ flowing.

$$\frac{I_{min.}}{I_{max.}}=\frac{1}{K}=K'$$

$$\frac{E_{max.}}{E_{min.}}=\frac{1}{C}=C'$$

$$C'K'=Z'=\frac{1}{Z}=\frac{1}{CK}$$

*See Fig. 2.

P = Number of steps.
R_T = Total resistance in circuit when the controller is on the first notch.
R_m = Resistance of motors and wiring.

From Fig. 1 it is seen that counter e.m.f.'s E_2 and E'_1 are generated at the same speed. Also to satisfy the conditions of acceleration assumed,—

$$\frac{E_2}{E'_1} = \frac{E_{max.}}{E_{min.}} = C' \text{ or } E_2 = C'E'_1$$

$$\text{Similarly} — \frac{E_3}{E'_2} = \frac{E_4}{E'_3} = \frac{E_5}{E'_4} = C'$$

Let R_1 = the total resistance required in circuit at start to allow $I_{max.}$ to flow. (Fig. 1).

$$\text{Then } R_1 = \frac{E_o}{I_{max.}} = \frac{E_o - E'_1}{I_{min.}} \ldots \text{ From which } \frac{I_{min.}}{I_{max.}} = K' = \frac{E_o - E'_1}{E_o} \text{ and } E'_1 = E_o(1 - K') \ldots\ldots (1)$$

$$R_2 = \frac{E_o - E_2}{I_{max.}} = \frac{E_o - E'_2}{I_{min.}} \ldots \text{ From which } \frac{I_{min.}}{I_{max.}} = K' = \frac{E_o - E'_2}{E_o - E_2} \text{ and } E'_2 = E_o(1 - K') + K'E_2 \ldots\ldots (2)$$

But from Fig. 2, $E_2 = C'E'_1 = C'E_o(1 - K')$

Then:—$E'_2 = E_o(1 - K') + C'K'E_o(1 - K')$

Likewise:—$E'_3 = E_o(1\text{-}K') + K'E_3$ and $E_3 = C'E'_2 = C'E_o(1\text{-}K') + (C'^2)K'E_o(1\text{-}K')$ or $E'_3 = E_o(1\text{-}K') + C'K'E_o(1\text{-}K') + (C')^2(K')^2 E_o(1\text{-}K') \ldots\ldots (3)$

Similarly:—

$E'_4 = E_o(1\text{-}K') + C'K'E_o(1\text{-}K') + (C')^2(K')^2E_o(1\text{-}K') + (C')^3(K')^3E_o(1\text{-}K') \ldots\ldots (4)$

$E'_5 = E_o(1\text{-}K') + C'K'E_o(1\text{-}K') + (C')^2(K')^2E_o(1\text{-}K') + (C')^3(K')^3E_o(1\text{-}K') + (C')^4(K')^4E_o(1\text{-}K') \ldots\ldots (5)$

Referring to Fig. 1:

$$r_1 = R_4 - R_5 = \left[\frac{E_o - E'_4}{I_{min.}} - \frac{E_o - E'_5}{I_{min.}}\right] = \frac{1}{I_{min.}}(E'_5 - E'_4) \ldots\ldots (6)$$

$$\text{or: } r_1 = \frac{(C')^4(K')^4E_o(1\text{-}K')}{I_{min.}}$$

Likewise:

$$r_2 = R_3 - R_4 = \frac{1}{I_{min.}}(E'_4 - E'_3) = \frac{(C')^3(K')^3E_o(1\text{-}K')}{I_{min.}} \ldots\ldots (7)$$

$$\text{Thus: } \frac{r_1}{r_2} = C'K' = \frac{1}{CK} = \frac{1}{Z} \text{ or } r_2 = Zr_1$$

Similarly:—

$r_3 = Zr_2;\ r_4 = Zr_3;\ \ldots\ldots r_n = Zr_{n-1}$

Therefore in the same way:—

$r_1 = ZR_m \ldots\ldots (8)$
$r_2 = Zr_1 = Z^2R_m \ldots\ldots (9)$
$r_3 = Zr_2 = Z^2r_1 = Z^3R_m \ldots\ldots (10)$
$r_n = Zr_{n-1} = Z^2r_{n-2} = Z^{n-1}R_m \ldots\ldots (11)$

In general if R_T equals total resistance in circuit (equals R_1, Fig. 1): $R_T = R_m + r_1 + r_2 + r_3 \ldots r_{n-1} = R_m + ZR_m + Z^2R_m + Z^3R_m + \ldots\ldots Z^{n-1}R_m$

$$\text{or:—} \frac{R_T}{R_m} = 1 + Z + Z^2 + Z^3 + \ldots\ldots Z^{n-1}$$

$$\text{and } \frac{R_T}{R_m} = \frac{1 - Z^n}{1 - Z}^{*}$$

$$Z^n = 1 - \frac{R_T}{R_m}(1 - Z).$$

$$\text{Log } Z^n = \text{Log}\left[1 - \frac{R_T}{R_m}(1 - Z)\right]$$

$$\text{Therefore:—} n = \frac{\text{Log}\left[1 - \frac{R_T}{R_m}(1 - Z)\right]}{\text{Log } Z}$$

But $n = P + 1$ where P = number of steps.

$$\text{Therefore:—} P = \frac{\text{Log}\left[1 - \frac{R_T}{R_m}(1 - CK)\right]}{\text{Log } CK} - 1 \ldots\ldots (12)$$

*$(1 + Z + Z^2 + Z^3 \ldots\ldots Z^{n-1})$ is a geometric series and will reduce to the form $\left(\frac{1 - Z^n}{1 - Z}\right)$

SERIES PARALLEL CONTROL

The formula as given by equation (12) is correct for straight rheostatic control. It is not absolutely correct for series parallel operation, due to the fact that the ratio $\frac{R_T}{R_m}$ changes slightly when the motors are changed from series to parallel connection. However, if this is neglected and if the transition point is considered as an acceleration step the number of steps in series and parallel will be equal.

If, however, this variation is taken into consideration and if the transition point is not used as an acceleration step the following formula for the number of steps required for series parallel operation may be derived.

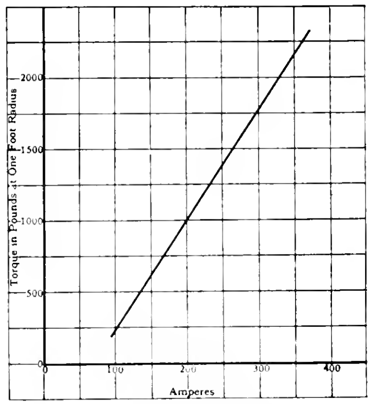


FIG. 3—VARIATION OF TORQUE WITH CURRENT

Let P_s = Number of notches required in series connection.
P_p = Number of notches required in parallel connection.
$\frac{R_m}{4}$ = motor resistance in parallel connection.
R_{gp} = external resistance in parallel connection.
R_m = Motor resistance in series connection.
R_T = Total resistance on first notch of series connection.

The equation for the number of steps required for the series connection is identical with equation (12).

For the parallel connection $R_{gp} = \frac{0.5E_o}{2I_{min.}} = \frac{E_o}{4I_{min.}} = \frac{KE_o}{4I_{max.}} = \frac{KR_TI_{max.}}{4I_{max.}} = \frac{KR_T}{4}$

and $R_{Tp} = R_{gp} + \frac{R_m}{4} = \frac{KR_T + R_m}{4}$ = Total resistance in parallel connection.

$$\text{Then: } P_p = \frac{Log\left[1 - \left(\frac{KR_T + R_m}{R_m}\right)(1 - CK)\right]}{Log\ CK} - 1 \ldots\ldots (13)$$

and: $P_o = P_p + P_s =$

$$\frac{Log\left[1 - \frac{KR_T + R_m}{R_m}(1 - CK)\right]\left[1 - \frac{R_T}{R_m}(1 - CK)\right]}{Log\ CK} - 2 \qquad (14)$$

Thus by substituting the necessary values into equations (8), (9), (10), (11), (12), (13) and (14) it is possible to determine the number and ohmic value of the steps required.

ENGINEERING NOTES

Conducted by R. H. WILLARD

Aim—To connect theory and practice

Parallel Operation of Three-Wire Generators

Connections for two three-wire machines in parallel are shown in Fig. 1. For parallel operation the commutating and series fields are divided and half the windings put on each side of the machine. This arrangement is necessary so that if all the load is between neutral and negative the current will still

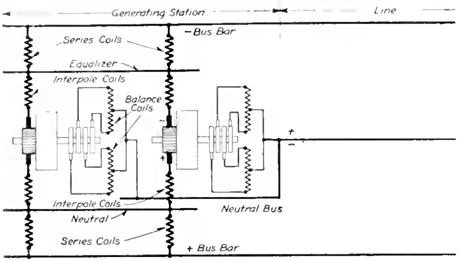


FIG. 1—CONNECTIONS OF THREE-WIRE GENERATOR

flow through part of the series and commutating fields. If the fields were not divided in this way the machine would not compound or commutate properly with unbalanced load, since part of the current would not flow through the series or commutating fields.

Synchronous Induction Motor

A special form of induction motor which runs at synchronous speed is used in some cases where only high torque is required. The primary is a regular winding to produce a rotating magnetic field, but the secondary has salient poles, i. e., projections of the core to correspond to the primary poles. This motor starts as a simple induction motor, but when nearly up to synchronous speed locks into synchronism because the salient poles on the secondary form a low reluctance flux path in comparison to the part of the secondary between poles so that, on account of the magnetic circuit tending to make the flux a maximum, the rotor locks into step. The torque available is not very great, but in most all salient pole machines operating as induction motors it is sufficient to drive the rotor at synchronous speed. This is true of self-starting synchronous motors and converters. It is immaterial whether the rotor is primary or secondary; in a converter it is the primary.

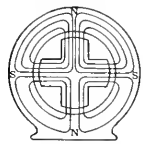


FIG. 1—SCHEMATIC DIAGRAM OF INDUCTION MOTOR WITH SALIENT POLES

As poles *N, S, N, S* travel around the stator frame the tendency to keep the flux a maximum causes the rotor to rotate in synchronism.

How to Babbitt Motor Bearings

CLEANING THE SHELL

Cast Iron, Malleable Iron or Cast Steel Shells (Untinned)—Remove all the old lining from the shell. This may be done by heating the shell sufficiently to melt out the old lining. Remove all oil, dirt or other foreign matter by dipping the shell in a solution of caustic potash or by burning. If the burning method is used, continue the burning until all smoke ceases, showing that all oil and dirt have been burned off; then scrape the surface with a file and rub down with coarse sandpaper in order to remove all scale and oxide.

Bronze, Pipe or Steel Shells (Tinned)—Remove the old lining by heating, preferably in a pot of scrap babbitt, and be sure not to heat above 375 degrees C. Just as soon as the old lining is melted out, swab the tinned surface with zinc chloride (a saturated solution of zinc in hydrochloric acid), then dip into a pot of "half and half" solder, which should be kept at a temperature not less than 340 degrees C. and not more than 375 degrees C. If shells are to be babbitted immediately, do not touch tinned surface after removing from the solder pot. If the shells are to be allowed to cool, brush off the tinned surfaces with a piece of clean waste.

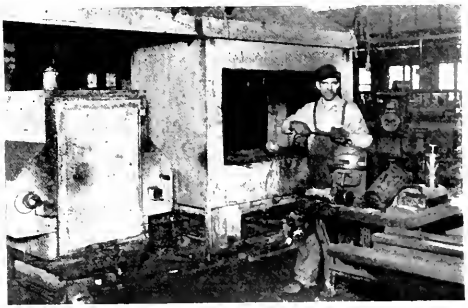


FIG. 1—AN EXPERT POURING BABBITT
Showing the correct method of holding and steadying the ladle during the operation.

TINNING

Bronze or Steel Shells—Paint the parts not to be tinned with a thin mixture of graphite and water. When dry swab the parts to be tinned with zinc chloride, then dip the shell into a pot of "half and half" solder, which should be kept at a temperature not less than 340 and not more than 375 degrees C. Leave the shell in the solder until it is just hot enough for the solder to run off, leaving a thin coating. Remove the shell from the pot and rub the surface to be coated thoroughly with a swab saturated with zinc chloride, then dip in solder again to wash off all traces of zinc chloride. If any untinned spots can be detected on the surface to be babbitted repeat the operation. If shells are to be babbitted immediately do not touch tinned surfaces after removing from the solder pot. If the shells are to be allowed to cool brush off the tinned surfaces with a piece of waste.

Steel shells must be pickled to remove the scale before being tinned.

PREHEATING OF MANDRELS AND SHELLS

Iron or Steel Sheels (Untinned)—Preheat the mandrel to a temperature of approximately 150 degrees and the shell to 100 degrees C. If the shell is heated too hot, the length of time for cooling may be so prolonged that the heavier metals in the babbitt will have time to settle to the bottom end of the bearing, in which case the metal in the one end of the bearing will be soft and in the other end brittle, while if the shell is too cold it will cool the babbitt too suddenly and cause it to shrink away from the shell. After each bearing is poured swab off the mandrel with a piece of waste which has been dampened with clay wash. This leaves on the surface of the mandrel a thin layer of fine clay dust, which has been found to be of great assistance in producing smooth, clean bearings free from pinholes and other surface defects.

Bronze or Steel Shells (Tinned)—Preheat the mandrel to about 100 degrees C. The same reasons for having the temperature correct apply here as given under Preheating of Mandrels for Iron or Steel Shells. After each bearing is poured it may be found necessary to cool the mandrel. This is done by dipping it in a clay wash, which leaves a layer of fine clay dust, the same as the swabbing for iron and steel shells. When the mandrel is at the proper temperature the water of the clay wash will evaporate very quickly on the surface of the mandrel, but will not spatter vigorously. The brass shell is preheated in the tinning operation and should be babbitted immediately after it has been tinned, before losing the heat given to it by the tinning operation.

FIG. 2—SELF-SKIMMING LADLES
Showing inside bridges for predetermining the size of the metal stream in pouring and for preventing slag from the top of the ladle getting into the bearing. Leather holders for these ladles are shown at the right.

MELTING

Melt the babbitt in an iron pot or kettle and maintain at a temperature between 460 and 470 degrees C. It is very necessary that this temperature be maintained when pouring bearings and that the upper temperature of 470 degrees C. be not exceeded at any time, as in certain grades of babbitt the metal is irreparably damaged if this temperature is exceeded. The use of an automatic regulator is necessary to hold the temperature within these limits. Stir the metal thoroughly at frequent intervals, otherwise the heavy metals will settle to the bottom of the pot. Keep the babbitt metal covered with charcoal or graphite to prevent oxidation.

POURING

Pour from a ladle in a steady stream directly down along the mandrel to avoid splashing or pocketing of air. The lip of the ladle should be kept free from burrs or other surface irregularities in order to pour a smooth, round stream. If the metal is splashed up against the mandrel it will cause blowholes and give a mushy bearing.

IN BRIEF

Pouring temperature for babbitt—460 to 470 degrees C.

Temperature of "half and half" solder for tinning—340 to 375 degrees C.

Preheat iron and steel shells—100 to 150 degrees C.

Preheat bronze shells in tinning operation.

Preheat mandrel for iron and steel shells—100 to 150 degrees C.

Preheat mandrel for bronze shells—100 degrees C.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1372—Synchronous Motors—Assume a 150 k.v.a., 2300 volt, three-phase, 60 cycle, 900 r.p.m. generator and a 150 k.v.a., 460 volt, three-phase, 60 cycle, 900 r.p.m. generator, and, furthermore, assume that these two generators are used as synchronous motors. What is the induced voltage on the revolving field of each at start under identical starting conditions;—that is, if each is started by a starter giving half normal voltage? What, in each case, is the voltage induced across the field windings at start? When running the above generators as synchronous motors is it satisfactory, as a temporary arrangement, to use water boxes in two of the three legs for starting; and if this device is used is the induced strain on the revolving field any greater than if used with an auto-starter? C. F. M. (VT.)

When a motor is started with the field winding at open circuit, the voltage induced in that winding cannot be calculated without knowing the design of the motor. With a machine of normal design and the characteristics given, assuming that the motor has a 125 volt field winding, the induced voltage is approximately 1500 volts. If the armature ampere turns and the field turns are the same for both machines, the same voltage will be induced in the field winding. This voltage is the result of the field turns cutting the flux produced by the armature current, and is proportional to the armature ampere turns and to the number of turns in the field winding. Sufficient torque to start the motor will not be produced with a starting equipment consisting of two water boxes connected in two phases of the motor, providing enough resistance is used to suitably limit the current. In this case, the phase voltages will be badly unbalanced and the current will produce but a small proportion of the torque that would be produced by the same maximum current and balanced voltages. If resistance is connected in each of three phases and so adjusted that the proper percentage of norma lvoltage is applied to each phase, the motor will start and the strain on it will be no greater than if it were started by means of an autostarter. The strain on the system will be greater, however, because the line current is the same as the motor current, the additional power being wasted in the resistances. It is a tedious and difficult procedure to properly adjust the water boxes, and because of this and the increased line power required this method should be used only when no other means of starting is available. R. K.

1373—Test for Grounds—Having no portable instruments for testing, what is the most convenient method of locating a grounded coil in an induction motor if direct current at low potential is available? Motors are all three-phase, 60 cycles, with squirrel-cage rotors, and range in size from one to sixty horse-power, there being 30 motors working. J. S.

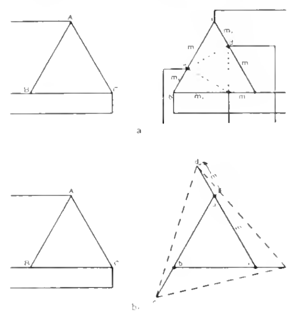
We assume these motors are connected to a line that does not exceed 250 volts. It will then be practicable to rig what is known in shop parlance as a "lighting out" line. This consists of a pair of insulated wires, with about one inch of the conductors bared and sharpened at one end, and the insulation reinforced with tape to form a handle. In series with one of these wires connect a sufficient number of lamps to equal the line voltage. The lamps should take about 50 watts at normal brilliance. Connect this line across one phase of the power line and, after separating the connections between phases, the grounded phase may be located by placing one sharpened wire on the frame of the machine where there is no paint. Touch the other against the bared connections. When the grounded phase is found the lamps will light nearly full brilliance. In like manner after opening the connections at various points in the winding of the ground phase it will be possible to locate the grounded coil by a process of elimination. This method must not be used for working on motors of high voltage, as there is too much risk to the operator in handling live leads of high voltage unless they are heavily insulated and provided with large insulating handles with insulating guards. The guards should be discs of insulating material about four or five inches in diameter made of a rigid material about one-quarter or three-eighths inch thick. They should be fitted on the insulating handles so that the fingers cannot come in contact with the bare ends of the conductors. J. E. M.

1374—Size of Rotary Converters—Will you kindly advise me what size of rotary converters to use to take the place of two 200 kw and one 60 kw, 230 volt, direct-current generators, the average day load being 1300 amperes; with lights on, 1600 amperes; momentary peak load, 1900 amperes? The above three units are all running when lights are on and the 60 kw is used at night for light loads. We use a balancing set in order to get 110 volts for the lighting circuit. Would you recommend a three-wire converter in place of the balancing set? S. P. J. (PA.)

For the above load we would suggest one 300 kw, 250 volt converter, and one 200 kw, 250 volt converter; the small machine to be three-wire to take care of the lighting load. The 300 kw machine would have a two-hour rating of 450 kw and the 260 kw machine of 250 kw. If the load is increasing so that additional capacity may be required in a reasonable time we would suggest two 300 kw machines. R. A. M.

1375—Transformer Taps—In Fig. 1375(a), *A, B, C* represent the primaries of transformers connected in delta; *a, b. c* represent secondaries of transformers; *d, e, f* are taps taken off. Ratio of $\frac{ad}{dc} = \frac{m_1}{m_2}$. With a given kw capacity, how do the currents divide in the various circuits? In Fig. 1375(b), which is the same as above except that taps are placed as shown, how do the currents divide in the various circuits? What precautions are necessary if three-phase, core type units are used instead of three single-phase units as shown above? S. C. (MONTREAL)

Let m_1 = the voltage between points *a* and *d* in both figures; m_2 = the voltage between points *d* and *c* in Fig. 1375(a) and between points *a* and *c* in 1375(b); E_{df} = the voltage between points *d* and *f*: I_{ad}, I_{dc} and I_{ac} = currents in windings between points *ad, dc* and *ac* respectively; and W = the total



FIGS. 1375(a) and (b)

three-phase load drawn from points *def* in volt-amperes. Then for Fig. 1375(a) $I_{ad} = I_{dc} = \frac{W}{3\,E_{df}}$ and $E_{df} = \sqrt{m_1^2 - m_1 m_2 + m_2^2}$. For Fig. 1375(b) $I_{ad} = \frac{W}{\sqrt{3}\,E_{df}}$ $I_{ac} = \frac{W}{3\,E_{df}}$ and $E_{df} = \sqrt{3m_1^2 + 3m_1 m_2 + m_2^2}$. The currents and voltages for the other phases are the same as for the phase that has been considered. A proof of these expressions is not given here on account of the considerable space that would be required. No greater precautions are necessary if three-phase core-type units are used, than for single-phase units. J. F. P.

1376—Grounded Motor—(a) Fig. 1376(a) shows diagrammatically the connections of a motor-generator set in a large generating station. On one occasion, on attempting to start up the set, the motor broke down as soon as

the starting switch was closed, several coils breaking down to ground. At the same time the ground-indicating lamps and lamp receptacles on the direct-current machine were blown to pieces and the main oil switch for the motor opened automatically, blowing off one oil tank. It was afterwards found that the 2200 volt main bus was badly grounded on one phase, but whether the ground was there before the attempt to start the motor was made or not is not known. An opinion as to what caused the burning of the lamps on the direct-current machine would be greatly appreciated. The distance between the centers of motor and generator is about three feet. Would the abnormal current taken by the motor cause an e.m.f. to be induced in the field coils of the direct-current machine? (b) On another occasion in the same plant, after all the apparatus had been pretty well soaked with water due to an accident in the power house, a water-wheel driven exciter was started up and, with about 50 volts showing on the direct-current voltmeter, the ground-indicating lamps on the machine were burning brilliantly white, showing that the lamps were each getting something like 140 or 150 volts. The direct-current voltmeter was found to be O.K. Can you explain where the voltage across the lamps was coming from? The lamps were connected in a manner similar to those shown in question (a). W. G. S. (CANADA)

(a) The information given in the question is not sufficiently complete to enable us to give a complete answer, but it is our opinion that the following explanation is correct. We are unable to see how any abnormal current in the motor winding could cause an e.m.f. to be induced in the field coils of the direct-current machine. It is more probable that the break-down of the motor coils found a lower resistance path to ground through the frame and brushholder

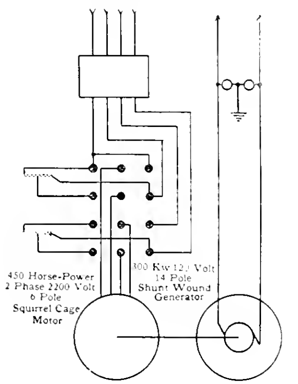


FIG. 1376(a)

part of the direct-current machine and through the ground-indicating lamps. We are expressing this opinion on the assumption that the motor generator set is mounted on a concrete base that is fairly dry and has a comparatively high resistance. This condition has been found to obtain in other installations, and to avoid difficulty in the future we would suggest grounding the frame of the set to some good ground around the power house. (b) There was probably sufficient leakage between the voltmeter leads to prevent full voltage on the voltmeter, although the exciter itself was delivering the voltage. Otherwise, the lamps on the frame would not have lighted up. F. C. H.

1369—Repulsion Motor—I am having trouble with a 2 hp, 60 cycle, induction repulsion motor which has had a complete new winding, data being taken from old winding. The motor when running has a loud rumbling noise and sparks bad at the energy brushes. It runs quietly when energy brushes are disconnected, but runs about 2400 r.p.m. G. H. P. (NEB.)

The energy brushes referred to are apparently the ones known as the compensating brushes. By lifting these brushes from the commutator the motor would run as a repulsion motor at an increased speed of from 2400 to 2600 r.p.m. By opening the energy circuit

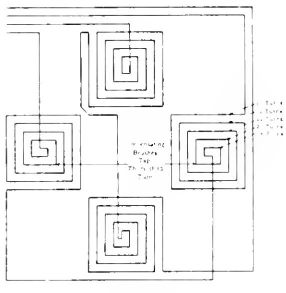


FIG. 1377(a)

(the short-circuited brushes) the motor would come to a standstill unless there is a short-circuit in the armature winding. In this case, and with the brushes removed, there would be no starting torque, but if the motor were started it would run at synchronous speed. The sparking at the brushes and rumbling noise would indicate over-compensation. From the diagram the bottom pole is connected wrong. The connection from the top pole should be brought to the small coil at the center of the pole instead of to the outside pole. With the connection as shown there would be 60 turns included in the compensating circuit of the bottom pole instead of 33. This would cause over-compensation, or too high voltage across the compensating brushes. To correct this it will be necessary to rewind the bottom pole, as by changing connections the bottom pole polarity would be reversed. L. W. S.

1378—Number of Poles—In changing poles on a stator of a wound secondary induction motor do you have to change also the poles on the stator as well? E. M. D. (WASH.)

Yes. The number of poles on the rotor must always be the same as on the stator. A. M. D.

1379—Charging Current—If unloaded transformer banks are connected to a transmission line, will the charging current be reduced from the value indicated when no transformer banks are connected? How is this condition allowed for when calculating charging current on a given transmission line? R. B. G. (CALIF.)

If unloaded banks of transformers are connected to a transmission line the charging current drawn from the generators will be reduced. The reason for this is that the charging current for a transmission line is at a low power-factor leading, while the magnetizing current for transformers is at a low power-factor lagging; consequently, the latter neutralizes part and sometimes practically all of the former. In calculating the regulation or current in a transmission line the magnetizing current for the transformers should be considered as a constant loads at a lagging power-factor of cos. θ, where tan. θ = true iron loss + exciting volt-amperes. J. F. P.

1380—Lightning Arrester Choke Coils—Should you consider that lightning arrester choke coils of either of the following dimensions, used on a trolley car and connected in series with the motor circuit, have sufficient self-induction to stop the discharge through its circuit of an induced lightning charge on the trolley wire; Coil *A*—14 turns, No. 00 wire on a four-inch wood core; Coil *B*—9 turns, No. 6 wire on a two-inch wood core? G. W. D. (MASS.)

Coil *A* has approximately a sufficient amount of inductance for street car service when the lightning is not of great severity, though it would be preferable to have a coil of greater inductance. Coil *B* has too little inductance to be of much value. We would reject coil *B*. We do not consider that any coil would entirely stop the passage of a lightning discharge. A choke coil should be considered as an auxiliary to a lightning arrester. A part of an incoming lightning surge would be passed through the coil. But with a very much broader wave front and much reduced in voltage, a part would be absorbed by the coil, while the main part of the surge would be reflected back onto the line, when it will travel back and forth until dissipated as I^2R losses on the line. A choke coil may be considered as a buffer or shock absorber. The degree of protection afforded by a choke coil varies directly as the inductance of the coil. G. C. D.

ADDENDA

The following paragraphs should be added to the article by Mr. Charles Fortescue, in the JOURNAL for September, 1916, p. 430:—

"A useful application of the diagram is for the determination of the amount of capacitance required at the end of a transmission line to maintain a constant voltage at any given load and power-factor. A circle is drawn with *O* as center and radius corresponding to the desired voltage, and the desired power circle is also drawn. The power-factor circle passing through the point of intersection of these two circles gives the resultant power-factor required. Then if Q be the wattless component of the load to be supplied and Q_0 that given by the diagram to maintain the required voltage, $Q - Q_0$ will be the condensive k.v.a. required at this point.

"The diagram may be used for a balanced polyphase transmission by considering it as the equivalent of a single-phase system of one-third the rating, considering the resistance and inductance corresponding to that of one wire to neutral and the voltage corresponding to that between one wire and neutral."

FINANCIAL SECTION

ELECTRIC RAILWAY SECURITIES

Electric railway corporations, both street and interurban, as well as the holders of their securities, are occupying a much more enviable position in the financial world this year than last. Last year, in addition to the loss in revenues caused by a long-continued business depression which was only just beginning to show improvement, the electric railways of the country were in the midst of the jitney competition, which was causing many companies large losses in revenues. By the opening of 1916 the general business of the country, especially that of the section east of the Mississippi, was in the full flow of prosperity and, in addition, the end of the jitney competition could be seen.

From the start of the jitney movement, the operation of motor cars at a five-cent fare was seen by all discerning men to be an economic impossibility, and it was predicted that wherever an attempt was made to operate them on any long hauls there would be a quick decrease in their number, and also that regulation, however slight, would also put them out of business. For a time dealers in second-hand cars and the makers of the cheaper class of motor cars heralded the jitney as the deliverer of the common people from the tyranny of the street railway and predicted that within a comparatively short time jitneys would largely take the place of the electric street car. However, it was soon found that the jitneys would operate only in rush hours, when they could secure a full load at once; also that they would not operate in rainy days or in cold, snowy weather, and that, whereas the street cars operated steadily and on a regular schedule, the jitneys observed only their own will in regard to schedules and routes. In addition, there was at once a great increase in street accidents, and when the situation became better understood there was almost a general call for their regulation. With regulation the jitneys began to disappear. There is not a city today where jitney regulation has been put in effect that they are operating, and it is only in the cities and towns where they are unregulated that they are now any menace to the revenues of the electric railways. The high cost of gasoline and motor accessories also affected the jitneys, but it was regulation that put them out of business. As soon as they had to observe regular routes and schedules, cease piling passengers on running boards and fenders and were compelled in other respects to operate at least to some extent on the same basis as the street railways they disappeared from the streets.

In Los Angeles, San Francisco, Portland, Seattle and a few other Pacific Coast cities, as well as in a few New England towns, they are still a factor in urban transportation, but already their decline is being seen in several of these places where there is some slight attempt being made at regulation. How much the jitney invasion cost the electric railways of the country in actual loss in revenues in the short time they were in general operation probably will never be known, but this was but small in comparison with the loss to investors by the decline in street railway securities, and to the companies in the high price the latter had to pay for new capital in the period the invasion lasted. Many frightened investors threw overboard at panic prices their street railway securities, despite the assurances from the best electric railway operators of the country that the competition could not last. By reason of the largely decreased price of their securities the companies were obliged to borrow money on short time and at high rates, thus further adding to their losses. Now, however, the jitney competition may be definitely said to have ended and, while they still exist in a few cities, their reign in these can be but short at the most and only until regulation places them under such control as other common carriers.

In the past year there has been a good recovery in the prices of street and interurban railway securities and, while these companies are not showing such large average gains in revenues as the electric light and power companies, their increases in revenues are most gratifying to the men who have never lost faith in the future of the electric railway industry.

How large the electric railway industry of the country really is has probably not been fully realized by the majority of people, even those directly interested in its operation. The latest available figures place the total capital invested in the electric railways of the country in excess of \$5 363 000 000, of which 50 percent is devoted to actual operation of the street railway lines and 50 percent to power generation, distribution and application. The electric railways of the country have annual operating revenues of more than \$700 000 000 a year and give employment to more than 330 000 men. In addition, there are electrified steam lines with investments of more than \$200 000 000 and employing more than 15 000 men on their electrified divisions.

Improvement in the revenues of the electric street and interurban railways of the country began in the last half of 1915 and has been steadily continuing since then. At present, from available statistics and returns from lines in all sections of the country, it is probable that operating revenues of the companies are averaging an increase of ten percent over corresponding period of 1915, while net operating revenues are increasing at an average rate of between 13 and 14 percent. The largest gains are being made in the section of the country east of the Mississippi and north of the Ohio river, while the section east of the Mississippi and south of the Ohio is also showing quite satisfactory increases. Because of the jitney competition still existing on the Pacific Coast, and also because general business conditions began to improve at a later date in that section, the western division of the country is not showing

FINANCIAL SECTION

as large gains, the average probably being around five percent in gross, with net running but slightly above that of a year ago. What this improvement in revenues means to the electric railways of the country may be seen when it is stated that 1915 was the worst year in a long period, when earnings of the electric railway lines are taken into consideration. It was the first year in the history of the industry in which a decrease in both gross and net revenues of the electric railways of the country was shown over the preceding year. These decreases were small when compared with revenues for 1914, in which, while a gain in gross was made over 1913, reported a slight decrease in net compared with that year. Of 272 electric railway companies reporting for 1915, with total gross of $513 967 674, compared with $514 028 402 in 1914, there were 148 which reported decreases totaling $10 726 907, while net revenues of the 272 companies were $194 893 975 in 1915, compared with $196 921 712 in 1914, a decrease of $2 027 737, or 1.03 percent. Of the 272 companies there were 131 reporting decreases in net revenues, these totaling $10 937 946. However, this showing will not be repeated in 1916, as enough is already known of the year's operation to make it certain that the electric railways of the country will show good gains in both gross and net over 1915 and probably will report the largest total earnings of any year in the history of the industry.

This rapid recovery in earning power has resulted in a much more favorable outlook for electric railway securities, and within the last six months both the demand and the price for these have been improving. The investors who held to their electric railway investments through the dark days of the last half of 1914 and the first half of 1915 now know that they made no mistake in refusing to sacrifice their holdings, and the men who bought street railway securities at their low prices in that period now have handsome profits to show as the result of their faith in the future of the industry.

The prices of the securities of many electric railway companies, however, have failed as yet to reflect the great advance in the earning power of the issuing companies, and in these securities may be found some great opportunities for the discriminating investor. There are a number of electric street and interurban railway securities which are still selling at low prices. While they were issued by companies of high earning power and with good credit, as yet the market has not realized how great a security there is behind a number of these issues. The very fact that, with but few exceptions, the electric railways of the country passed through the most trying period of their history without disaster, should give additional strength to their bonds especially. Of course, there were some fatalities among a few of the weaker corporations, but in every instance the companies were either improperly financed or improperly handled from an operating viewpoint and not prepared for a storm of any magnitude.

The companies which have been tested by the last two years and have come through with unimpaired and now steadily increasing earning power and with good credit have a right to ask for the confidence of the investors of the country. There are still many problems before the electric railway financiers and operators of the United States, but these are being worked out, and from now on there should be a growing prosperity among these companies and a steady growth in the market position of their securities. With steadily increasing revenues, with the general regulation of jitneys and, for this reason, their practical disappearance as factor in urban transportation, with increasing credit in security markets, with ability to secure capital on lower and easier terms, and with improvements in methods of transportation which are now being worked out, securities of electric railway corporations must again become popular. It will take some time to overcome all the ill effects of the last three years, but we firmly believe that the investor who makes a discriminating selection of electric railway securities at their present prices will find within a few years that he has not only been receiving a good rate of income on his invested capital, but at the same time will see that capital largely increased by the enhancement in the market value of his holdings.

WHY ELECTRIC PLANT EARNING POWER HAS GROWN

With many of the smaller electric generating and distributing companies of the country showing gains in earnings from light and power sales running from 30 to 50 percent over a year ago, it is being asked by investors not familiar with the causes for the rapid increase in business of these properties how such a showing is possible. Many of these investors have the idea that the growth of earning power in this class of properties should be largely in line with the increase in population, forgetting the many new uses for electric current being found almost daily, and also that the more progressive companies have been putting into effect extremely active campaigns for new business. As showing how revenues of these companies have been gaining, one of the latest combinations of several independently operated plants may be taken as an example, it also being of interest as one of the newer subsidiaries of Cities Service Company. In 1912 the three separate plants serving Elyria, O., were acquired by this organization and these, with others, have been combined to make up the Lorain County Electric Company, serving electric current to Elyria and Lorain, O., and three smaller communities. Lorain now has a population of 35 000, having increased from 5000 in 1890, while Elyria has 22 000, an increase from 14 500 in 1910. Before the consolidation of the separately-operated properties almost all the large power users had installed their own electric plants because of the inability of the local companies to furnish an adequate amount of power. In 1913 there was but 1000 kilowatts capacity in the plants; in 1913 this was increased to 3500 kilowatts, with a further increase of 7500 kilowatts in 1915, and by the end of this year the central generating station will have 14 000 kilowatts capacity. Centralization of management and generation of energy has resulted in an average decrease of 30 percent in the cost of current for both light and power to the consumers. The number of customers has more than doubled and, for the year ended July 31, 1916, sales of current totaled 11 505 908 kw-hrs. compared with 7 044 817 kw-hrs. in the 12 months ended July 31, 1915, a gain of more than 63 percent in the year. As soon as the centralization of power supply was completed the company began a campaign for the business of the industrial companies which had their own generating plants, and much progress has been made in this. Some of the largest consumers of the company are the Baltimore & Ohio Railroad, taking 3600 horse-power, and the Elyria factory of the Willys-Overland, taking 3000 horse-power. The record of this company operating in several small industrial communities shows graphically how similar companies are able to show such large gains in revenues, and the men most familiar with the electric generating and distribution business say that the progress made in the last two years is only a slight indication of the much greater progress that will be made in the coming five years.

GROWTH IN CENTRAL STATION BUSINESS

Engineers of central station light and power companies are predicting the greatest era of expansion within the next two years in the history of these companies. These men say that because of the developments now going on in the progress of electric heating that, where in small manufacturing towns 5000 kilowatts generating capacity in a central station is considered ample, it will not be long until the same towns will require from 20 000 to 25 000 kilowatts generating capacity.

The electric furnace now seems to be coming into its own, and in 1916 the United States came into first place in the countries of the world in the number and size of these furnaces in use, and their installation is only in its infancy as yet. One of the largest brass and copper melting and rolling plants in the country is preparing to entirely abandon the use of coal as fuel and to install electric furnaces instead.

The central station industry, which almost since its organization has been largely a domestic proposition serving light and domestic and commercial power, now appears at last to be coming into its own in the industrial field, and men close to the industry expect that in the next few years there will be the greatest growth ever recorded in the central station generating and distributing industry.

AMERICAN ELECTRIC RAILWAY ASSOCIATION ANNUAL CONVENTION

The thirty-fifth annual convention of the American Electric Railway Association will be held on Young's Million-Dollar Pier at Atlantic City, October 9-13. Present indications are that this meeting will be an especially important and well-attended one. The convention program as announced is as follows:—

MONDAY, OCTOBER 9—9:30 A. M. TO 12:30 P. M.—Registration and distribution of badges.

2 TO 5 P. M.—Annual addresses of presidents, annual reports of executive committees, annual reports of secretary-treasurers, appointments of convention committees of Transportation and Traffic Association, Engineering Association, Accountants Association and Claims Association.

Reports of Committees—(a) Standards, (b) Construction of Schedules and Time Tables.

Paper — "Development of Schedule Makers," H. E. Donecker (*T. & T.*)

Reports of Committees—(a) Power Distribution, (b) Standards, (c) Special Sub-Committee on Stranding Cables (*Engineering*).

Paper — "The Statistician," W. E. Jones. Reports of Committees—(a) Accounting Definitions, (b) Standard Classification of Accounts, (c) Representing Association at Convention of Railroad Commissioners (*Accountants*). Paper—"Commission Valuation of Pubblic Service Properties for Purposes of Rate Regulation," John E. Benton (*Accountants*).

Reports of Committees—(a) Employment, (b) Ways and Means (*Claims*).

Paper — "Workmen's Compensation Account," Roy C. Green and L. S. Hoffman (*Claims*).

4:30 TO 5 P. M.—Report of Committee on Claims—Transportation (*T. & T. and Claims*).

TUESDAY, OCTOBER 10—9:30 A. M.—Annual addresses of presidents, reports of executive committees, reports of secretary-treasurers. Appointment of committees on resolutions, nominations, on president's recommendations. Reports of Committees — (a) Convention, (b) Education. Addresses—"Electric Railways and Preparedness"—(a) Maj. Gen. Leonard A. Wood, (b) Capt. S. E. Embick. Reports of Committees—(c) Representing Association American Good Roads Congress, (d) National Joint Committee on Overhead and Underground Line Construction, (e) Company Membership, (f) Valuation. Paper—"Unit Costs and Overhead Charges." Reports of Committees — (g) Federal Relations, (h) Compensations for Carrying United States Mail (*American*).

TUESDAY, OCTOBER 10—2 TO 3:30 P. M.—Reports of Committees — (a) Engineering—Accounting, (b) Life of Railway Physical Property (*Engineering and Accounting*).

Reports of Committees—(a) Passenger Traffic, (b) Uniform Definitions. Paper—"Training Men for Supervision and Executive Positions," L. C. Bradley (*T. & T.*)

3:30 TO 5 P. M.—Address—"Commission Accounting Inconsistencies," H. A. Dunn. Paper—"The Federal Census of the Electrical Industries," W. K. Stewart (*Accounting*).

Reports of Committees — (a) Block Signals, (b) Transportation—Engineering, (c) Standards (*T. & T. and Engineering*).

Paper — "Near-Side Stop," John J. Rennels and S. B. Hare (*Claims*).

WEDNESDAY, OCTOBER 11—9:30 A. M.—Reports of Committees — (a) Electrolysis, (b) Company Sections and Individual Memberships, (c) Award of Company Section Medal, (d) Conditions of Awarding Brady Medal, (e) Public Relations. Address, "Publicity," Ivy L. Lee. Reports of Committees—(f) AERA Advisory Board, (g) Changes in Constitution and By-Laws, (h) Operation of Motor Vehicles, (i) Insurance, (j) Standards for Car Loading, (k) Street Traffic (*American*).

WEDNESDAY, OCTOBER 11—2 TO 5 P. M.—Reports of Committees—(a) Cost of Rush-Hour Service, (b) Fares and Transfers. Prepayment Systems—Discussion. Report of Committee — (a) Express and Freight Traffic (*T. & T. and Accounting*).

Reports of Committees—(a) Power Generation, (b) Standards, (c) Way Matters (*Engineering*).

Paper — "Automobile Accidents and Traffic Regulations," H. G. Winsor and A. G. Brown (*Claims*).

THURSDAY, OCTOBER 12—9:30 A. M.—Report of Committee — (a) Taxation Matters. Address—"The Physical Development of Electric Railways," Frank J. Sprague. Address—"The Financial Development of Electric Railways," A. B. Leach. Reports of Convention Committees—(a) President's Message, (b) Resolutions, (c) Nomination, Election and Installation of Officers (*American*)

THURSDAY, OCTOBER 12—2 TO 5 P. M.—Reports of Committees—(a) Claims—Accounting (*Accounting and Claims*)

Address—"The Part Which Accounting has played in the Development of Modern Industry," J. R. Wildman. Address—"Some National Issues in Local Street Railway Franchises," C. L. King. Reports of Committees — (a) Resolutions, (b) Nomination and Election of Officers (*Accounting*).

Report of Committee — (a) Rules. Company Publications—(a) Their Use and Value, (b) Their Preparation and Publication (*T. & T.*)

Reports of Committees — (a) Equipment, (b) Standards Buildings and Structures. Paper—"The Lighting of Cars" (*Engineering*).

Paper—"Claim Work," E. P. Walsh and C. G. Rice (*Claims*).

FRIDAY, OCTOBER 13—2 TO 5 P. M.—Reports of Committees—(a) Heavy Electric Traction, (b) Standards, (c) Electrolysis. Election and Installation of Officers (*Engineering*).

PERSONALS

Mr. Peter Junkersfeld, assistant to the vice president of the Commonwealth Edison Company, Chicago, was elected president of the Association of Edison Illuminating Companies at its thirty-seventh annual convention at Hot Springs, Va., September 4-7

Mr. L. H. Haight, of the New York district office of the Westinghouse Electric & Mfg. Company, has resigned and accepted a position in the New York sales office of the Ward-Leonard Electric Company, of Mount Vernon, N. Y.

Mr. Arthur J. Sweet, well known as an illuminating engineer and who for several years has been a member of the consulting engineering firm of Vaughn, Meyer & Sweet, will conduct a general consulting engineering business in steam and electrical engineering, as well as in his specialty of illumination, with offices in the Palace Theater building, Milwaukee, Wis.

Mr. Samuel Insull, president of the Commonwealth Edison Company, Chicago, has been elected chairman of the board of directors of the reorganized Chicago & Milwaukee Electric Railway Company, which is to be known hereafter as the Chicago, North Shore & Milwaukee Railway Company.

Messrs. F. B. H. Paine, William McClellan and H. T. Campion have formed a consulting engineering partnership under the firm name of Paine, McClellan & Campion, with offices at 25 Church street, New York, and 1420 Chestnut street, Philadelphia.

Mr. C. E. Skinner, in charge of the research engineering department of the Westinghouse Electric & Mfg. Company, has been appointed a member of the Edison Medal Committee by the American Institute of Electrical Engineers.

Mr. W. F. Kleine, of the New York district office of the Westinghouse Electric & Mfg. Company, has resigned to accept a position in the New York sales office of the Northwestern Electric Equipment Company.

Mr. W. P. Allen, inspector of signals of the Pennsylvania Railroad, resigned to accept the appointment as resident manager of the New York office of the Union Switch & Signal Company.

Mr. Walter N. Wamsley, formerly general manger of the Sao Paulo Tramway, Light & Power Company, has been appointed general manager of the Alabama Power Company.

Mr. Edgar A. Loew, assistant professor of electrical engineering at the University of Washington, Seattle, has been promoted to an associate professorship.

Mr. Roy E. Schaulin, formerly of the Westinghouse Lamp Company and for the past three years a member of the business staff of the *Electrical World*, has resigned to accept the position as manager of the New York office of the Franklin Electric Mfg. Company, of Hartford, Conn.

Mr. H. P. Williamson, of the Robertson-Cataract Company, of Buffalo, N. Y., has resigned to become connected with the Chicago district office of the Westinghouse Electric & Mfg. Company.

Mr. Wesley C. Picker, of the commercial training department of the Westinghouse Electric & Mfg. Company, East Pittsburgh, has accepted a position with the Detroit district office of the company.

Mr. Guy L. Bayley, who was chief of the mechanical and electrical departments of the Panama-Pacific Interna-

tional Exposition, has opened an office as consulting engineer in the First National Bank building, San Francisco. Mr. Bayley is at present engaged in building an hydroelectric plant for the Department of the Interior in the Yosemite Valley on the Merced river.

Mr. N. M. Overall, of the Houston (Tex.) office of the Westinghouse Electric & Mfg. Company, is now located at the Pittsburgh district office of the company.

Mr. Trygve D. Yensen, formerly of the engineering experimenting station of the University of Illinois, has accepted a position in the research department of the Westinghouse Electric & Mfg. Company at its East Pittsburgh works.

The article by Mr. David Hall on "The Compensated Generator," which appeared in the JOURNAL for August, is reprinted in *The Practical Engineer* for September 15, 1916.

The editorial entitled "Silent Inefficiency," published originally in the JOURNAL for July, 1916, appears as an editorial in *The Isolated Plant* for September, 1916.

NEW GROUNDING DEVICES

A new grounding device has been placed on the market by Hickey & Schneider, 61 Broadway, New York, called the Burn-Boston carbon ground. This is composed of a solid carbon electrode which is non-porous and is surrounded by a carbonaceous mixture which is porous and moisture-absorbing. The grounding device is in the shape of a long upright cone, so that the pressure of the earth will compact closely against it. At the top is a copper lug for connection to the circuit. It is claimed that this form of grounding cone eliminates entirely electrolysis, which is one of the causes of deterioration in many forms of grounding devices. As a ground which is ineffective is worse than useless, the importance of this new development is evident. The fact that these grounds are placed on the market to sell at $1.50 each should also be attractive to operating companies.

ORDER FOR LARGE TURBINE

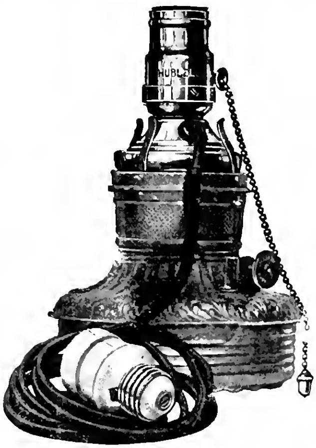
A 20 000 kw, 11 000 volt, 25 cycle turbine unit complete with a 24 000 sq. ft. surface condenser and auxiliaries has recently been ordered by the Pennsylvania Railroad from the Westinghouse Electric & Mfg. Company, of East Pittsburgh, Pa. This turbine is for installation in the railroad's Long Island City power house, which supplies power for the operation of the Pennsylvania Terminal and the Long Island Railroad.

INSULATING CABLES WITH CONDUCELL AND CONDULINE

The *Conducell* method of insulating cable joints in underground distribution systems by the use of factory-formed insulation, in conjunction with the *Conduline* filling compound, as described in the two latest bulletins of the Mica Insulator Company of New York and Chicago, has many unique features. It eliminates uncertainties as to the dielectric quality of the joint and makes it as dependable as the cable itself. The *Conducell* method consists of placing the factory-formed insulation, requiring only mechanical assembly, between and around the conductors, and leaves no choice to the workman as to thickness and relative location of the parts. The *Conducell* insulators are made of micanite in various sizes to suit all cables. *Conduline* is a special compound used with the *Conducell* process for filling and sealing the joints of cables after the *Conducell* units are placed on the cable joints. The peculiar characteristic of this compound with respect to viscosity and hardness in relation to temperature makes it an ideal joint-filling substance. Bulletins describing this new method may be obtained by addressing the Mica Insulator Company, 68 Church street, New York City.

ELECTRICAL ATTACHMENT FOR OIL LAMPS

An interesting and rather unusual device is the No. 5403 oil lamp attachment which is shown herewith mounted in a Rochester burner and which is adapted for use with any type of oil lamp having a common burner either of the flat wick or central burner type. As shown, the attachment can be sprung down in



OIL LAMP ATTACHMENT

the same manner as the lamp chimney and current taken from any nearby socket or receptacle, thus converting the oil lamp to an electric lamp. If so desired, the lamp may be immediately converted back for use with oil, as the attachment of the device does not interfere in any way, it is stated, nor are tools required to attach or detach. It is provided with seven feet of cord and a new style porcelain attachment plug which was recently described in these columns. The device has been brought out by Harvey Hubbell, Inc., Bridgeport, Conn.

THE ELECTRICAL POSTER EXHIBITION

Under the auspices of the Pittsburgh Advertising Club and through the courtesy of the Carnegie Institute of Technology, the two hundred drawings submitted by artists all over the country in the recent poster exhibition held by the Society for Electrical Development, Inc., of New York City, will be exhibited for one week, in the early part of November, at the Carnegie Institute of Technology, Pittsburgh. Unusual interest has been shown throughout the country in this traveling exhibit, it having been or will be shown in Boston, New York, Philadelphia, Atlantic City, Baltimore, Milwaukee, Cincinnati, Cleveland and, after the Pittsburgh exhibition, in other cities, there being many requests for it. Anyone interested in the advertising and sales department of electrical concerns should make it a point to see these posters, many of which were drawn by the best commercial artists in the country. Invitations will be sent to all organizations interested in electrical development in the Pittsburgh district as soon as the date has been definitely fixed. The committe in charge of the exhibition is R. L. Forsythe, Sherman Smith, G. B. Martin and H. R. Fielding and H. L. Gage, Director of the Department of Printing, Carnegie Institute of Technology. J. Tyrone Kelly is chairman of the Poster Committee for the Society for Electrical Development, Inc.

NEW BOOKS

"Steam Power"—C. F. Hirshfeld and T. C. Ulbricht. 420 pages, 232 illustrations. Published by John Wiley & Sons, New York City. Price $2.00.

This is one of the Wiley technical series of books for vocational schools and is an attempt to collect in a comparatively small book such information regarding steam power as should be familiar to engineers whose work does not require that they be conversant with thermodynamic principles. Mathematic treatments have been eliminated to the greatest possible extent, only elementary algebra being used. Beginning with a chapter on heat-power and on steam, discussions are given on the ideal steam engine, the entropy diagram, the real steam engine with detail illustrations of parts, the indicator diagram and its use, compounding, high-efficiency engines, regulation, a short discussion of the steam turbine, also of condensers and related apparatus. The subject of combustion is given considerable attention, also fuels, steam boilers, the latter section being profusely illustrated with typical boiler layouts. The final chapters are devoted to the recovery of waste heat, boiler feed pumps and auxiliaries.

"Electrical Motors, Direct and Alternating"—David Penn Morton. 241 pages; 115 illustrations. Published by Frederick J. Drake & Co., Chicago. Price $1.00.

This book is prepared particularly for the practical man. The first three chapters treat the fundamental principles of electric and magnetic circuits. The common methods of measuring current, pressure, resistance and power are explained in Chapter IV. Chapters V and IX are devoted to armature windings, particular attention being given to defining common terms. Chapters VI, VII and VIII are devoted to the different types of direct-current motors, their characteristics, repair, etc. Chapters X, XI and XII are devoted to the different types of alternating-current motors, the discussion being given along the same general lines as for direct-current motors. A number of examples, with their solutions, are given throughout the book to illustrate the application of working principles and to assist the reader in getting a clear understanding of the subject.

THE ELECTRIC JOURNAL

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Steel Mill Electrification Motor drive for the main rolls of steel mills was first used in this country about ten years ago, and for a period of eight years the number of installations per year averaged 25 units, totaling 33 750 horse-power, including 300 horse-power motors and larger. During the last two years the number of installations has increased very rapidly, including approximately 125 units, totaling 265 000 horse-power, which represents an addition of more than 65 percent of the drives installed from 1906 to 1914. The demonstrated advantages of motor drive which the several years of experience has made positive and convincing are thus rapidly leading to its universal adoption in mill work.

A further analysis, with respect to reversing mills, gives very substantial evidence of the exceptional advantages of motor drive for this particular type of mill. More than seventy-five percent of the new blooming mills added during 1915 and 1916 are designed for motor drive. Other types, such as universal plate mills, structural mills, billet mills and flat mills, are included in the list of reversing equipments, totaling 12 units.

There is more economy of operation to be gained by the electrification of the reversing mill than of any other type. Some very interesting data is available from the several reversing mills in operation, which show marked increase in efficiency, not only from the standpoint of steam consumption, but also of general improvements in the operation of the mill with the result of increased tonnage and reduced cost of production.

A great deal of attention is given today to the subject of scientific management, which is largely based on a detailed analysis of operations. The motor-operated reversing mills are giving the steel industry a most practical demonstration of the value of electric drive in connection with this idea, for it makes convenient and easy the obtaining of complete records of power requirements, and costs of power, of repairs and of maintenance, in order to determine production costs accurately. Graphic power records also assist materially in the development of the general design of the mill, serve as a check on mill friction and indicate immediately and positively unfavorable operating conditions. Prompt attention to these matters will often result in a considerable saving of power and mill maintenance and eliminate serious trouble.

The steel mills of this country are working to a very high capacity. Tonnage is the most important item, and this undoubtedly means that many mills will have to be repaired in a very thorough manner in the near future. In the majority of cases the drive can be remodeled to advantage, adopting a unit of increased capacity to be consistent with the other general improvements which have been planned to increase the mill capacity. When the time comes to decide definitely the details of the new drive the mill management should keep in mind the idea of constructive improvement, not in respect to the one or more mills in question, but of the entire plant.

Motor drive is particularly attractive, because the advantages afforded in any one plant increase as its application is extended. It is for this reason that it is important and advisable to plan for the future betterment of the plant as a whole and work back to the individual mill in order to establish the true value of the improvement contemplated. In the rebuilding of existing mills, the electrification of the reversing mills will give the greatest returns on the investment and, in the majority of cases, will merit first attention. The records show that for entirely new plants or extensive improvements, motor drive is selected almost without exception.

BRENT WILEY

The Wonders of the Commonplace It is reported that a renowned scientist admitted to a few of his friends that after a lifetime of study he was still unable to understand the electric light. Whereupon his host explained:—"It's perfectly simple. You press this button—so, and the lamps light. You press this other button and the lamps are extinguished. That's all there is to it."

It must be admitted that to many of its users the telephone is equally simple. One lifts the receiver, gives a number and converses with a friend. Small wonder that, when the process seems so simple, exasperation should be felt when the thing goes wrong, and insists that the "line is busy" or the "party doesn't answer."

In reality, however, the telephone is not so simple. To obtain even a general idea of the elaborate and costly mechanism whereby, within a few seconds, any one of many thousand telephones can be connected to any other, and suitable signal service provided, requires either a visit to an exchange, or careful perusal of a description such as that by Mr. F. K. Singer in this issue of the JOURNAL. To understand the operation of the various devices in detail requires long study and a knowledge of the basic principles of electrical engineering. And it is only from a comprehension of the exceedingly minute and rapid variations of current that are required to transmit a range of voices from bass to soprano, with all the varied overtones which produce voice individuality, and of the tremendous difficulties of transmitting such variations of current unimpaired through hundreds of miles of underground cables and overhead wires, that one is able to realize the marvelous display of ingenuity that lies back of that everyday, commonplace instrument—the telephone.

CHAS. R. RIKER

The Grant Telephone Exchange, Pittsburgh

A TYPICAL TELEPHONE CENTRAL OFFICE INSTALLATION OF THE MOST MODERN METROPOLITAN TYPE

F. K. SINGER
Supervisor of Maintenance,
The Central District Telephone Company

THE visitor to the new Grant building of the Central District Telephone Company in Pittsburgh usually makes two inquiries:—"Why is a building of such size required?" and "Why was this particular site selected?" Something quite elemental in the furnishing of telephone service enters into both. Most careful studies show that a great city's need for telephone service can best and perhaps only be served when there are established a sufficient number of what are known as "central office areas" within the community, each with its own switchboard equipment, with connections to every other, and all woven into the whole fabric of the city's intercommunication. So the Pittsburgh exchange area is served by 21 central offices, and the Grant building is the newest, the most modern and perhaps the best of Pittsburgh's 25 telephone buildings.

In constructing the highways of the telephone in Pittsburgh, now embracing about two hundred and twenty thousand miles of wire, two of the principal arteries of the underground plant were laid years ago north and south on Cherry Way and east and west on Seventh Avenue. And, as the old building at 416 Seventh Avenue and its equipment became inadequate, the new structure naturally took its location near the intersection of these two cable arteries and at a point which is not only approximately in the center of the Grant central office area, but adjacent to the then existing structure and equipment.

The new building, while it now houses but one central office switchboard, is built for the future as well as for the present. Several years ago there was undertaken in Pittsburgh a development study on which was determined a fundamental telephone plan for the city. Estimates were necessary, of course, but they were based on careful computations and analysis; and so there exists today a "picture" of the city twenty years hence—its population, the distribution of that population, its building development and its property values. So, too, the underground telephone plant of the future is plotted out, the switchboard sizes and locations anticipated, and the development of the art forecasted. In sum and substance, this development study, checked continually against each year's results, permits the engineers to look always ahead. The Grant building was not designed without careful reference to Pittsburgh's fundamental telephone plan; and while it now houses several hundred employes engaged in a variety of telephone work, the next generation will find the new Grant switchboard augmented by two other central office boards of like size, each with its terminal room equipment, rest rooms and dining rooms for the operating forces, occupying substantially the entire ten floors, and the personnel of the building will then have become almost entirely operating in character.

FIG. 1—THE NEW GRANT EXCHANGE BUILDING

GENERAL DESCRIPTION

The building was designed with the primary purpose of housing telephone central office equipment. All of the structural steel work is extremely heavy, one column in particular weighing nearly a ton per foot for a section of 38 feet. This unusual strength is necessitated by reason of the heavy loads carried; on some of the floors, containing or hereafter to contain central office equipment, the required capacity per square foot is 325 lbs., as against 125 lbs. to 150 lbs. for the usual office building.

As compared with ordinary business structures, telephone buildings present numerous points of dissimilarity. As an example of its type, the new Grant building includes several features of design which at once attract attention.

First, there is the large amount of natural light and ventilation afforded by confining the building width to 40 feet and providing nearly 500 windows. The general construction is of steel framing with tile-arch floors

and "curtain" walls—walls built in between the steel work of adjacent floors and supported by this steel, thus making them independent of the walls on the other floor.

The fire protection consists of a water tank on the roof and an automatic centrifugal pump in the basement capable of delivering 750 gallons per minute at 125 lbs. pressure; also there is a liberal distribution of fire hose and chemical extinguishers throughout the building. The fire escapes—of which there are two, one at the front and one at the rear—are both of the enclosed type, the entrances being through outside "smokeproof" balconies at the floor levels. The only wood used in the construction is found in the hand rails of one stairway; the doors are steel and windows are set in steel sashes, supported in steel frames. All windows exposed to any fire hazard are paned with wire glass. The main stairway is completely isolated by metal fire doors, as are the entrances to the fire towers. Automatic self-releasing latches are used on these doors, which open when appreciable pressure is exerted against the bar of the latch, extending the full width of the door. The equipment floors contain scuppers or pipes with check valves carrying water from the floors to the outside wall, thus minimizing water damage should a fire hose be turned into the building. Outlets for telephone wires are so spaced on each floor that a desk may be placed in any position in any room and have a connection for telephone service under it.

The power and artificial light are normally derived from two separately routed circuits from the Duquesne Light Company, a 2200 volt alternating-current and a 550 volt direct-current circuit. The largest motors are two-phase, 220 volt, with the exception of the six elevator motors, which are 550 volt direct current. A single-phase circuit is used for lighting and in the operation of fans and other small motors. For emergency use, two gas-engine units are mounted in the basement on a seven-foot foundation, high enough to clear a river stage of 47 feet. One of these is a three-cylinder, 125 hp Westinghouse engine direct coupled to a 75 kw generator; this unit is designed to be used for the operation of machines connected to the two-phase power circuit, such as the pneumatic tube motors, the air compressors, the refrigerating machine, the drinking water circulating pump, battery charging machine motors, and so on. The other is a three-cylinder Nash engine, coupled to a 30 volt, 1000 ampere direct-current generator, which can be used for charging the storage batteries directly. This emergency equipment is obviously for use in case the outside power should fail. All of the operating quarters are equipped with gas arcs, in addition to the electric lighting,—and therefore the combined loss of the two feeder circuits and gas supply must occur before there can be any interruption of telephone service. Further, the storage battery equipment, the main battery of which has a capacity of 620 amperes for eight hours, has sufficient total capacity to supply the switchboards for from twelve to twenty-four hours, according to the state of charge.

The power equipment is all electrical, and the purchase of power from outside sources tends to absolute quiet and cleanliness. Electric vacuum cleaners, scrubbing machines and the usual complement of addressographs, calculating machines, etc., are used.

The lighting is semi-indirect throughout, thus insuring an even distribution of light; 100 and 200 watt nitrogen lamps are used. The elevators are equipped with complete safety apparatus and, of course, telephones. Taken altogether, the building represents a type which, although partially that of an office building at the present time, can gradually be converted into an equipment building in its entirety.

FUNDAMENTALS

The prime mechanical requirements of telephone operation, in addition to the telephone itself, are two:—a wire system furnishing a commercial grade of transmission between any two telephones within it, and such supple-

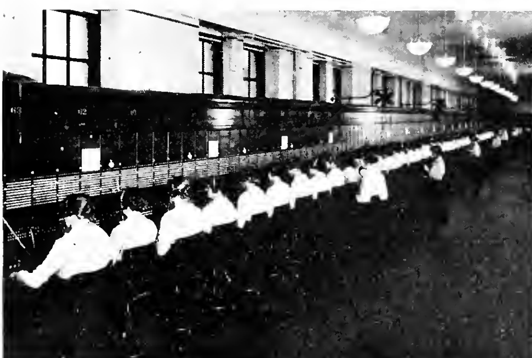


FIG. 2 (above)—THE "A" SWITCHBOARD AT GRANT

All of the 64 positions occupied. The supervising operators are standing.

FIG. 3 (at right)—THE "B" SWITCHBOARD

Chief operator's desk in foreground. The 15 000 telephones in the Grant central office area originate 75 000 calls daily, and the incoming traffic is nearly as heavy.

FIG. 4 (at right)—THE WIRE CHIEF'S DESK IN THE TERMINAL ROOM AT GRANT

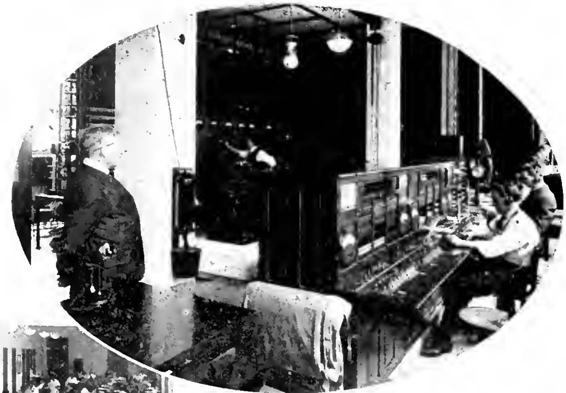
Here is maintained supervision over the complete wire system of the central office.

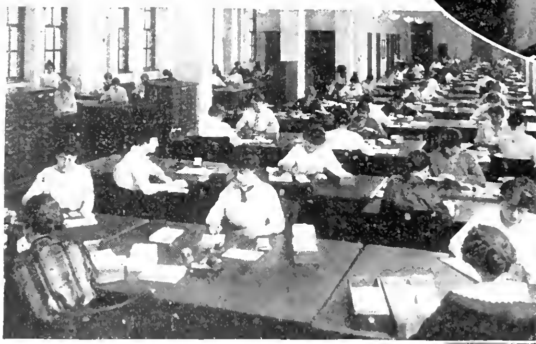
FIG. 5 (lower left)—A TYPICAL CLERICAL OFFICE IN THE ACCOUNTING DEPARTMENT

The building's 500 windows afford ample natural light.

FIG. 6 (lower right)—A CORNER OF THE PLANT DEPARTMENT

The building now houses 800 employes, in addition to the operating force.





mental equipment as provides a means of connection and disconnection and the signaling therefor.

As to the wire system itself, and its manual manipulation, a rather brief explanation must suffice; though when it is considered that one telephone expert has compiled a textbook of over two thousand pages describing only the fundamentals of telephone practice, it will be appreciated that any adequate explanation must be of some length.

In a city such as Pittsburgh, the plant of a telephone company comprehends much more than the lay mind would suppose, for the telephone instrument itself, with its bell box and wiring complete, represents only something like two percent of the plant involved in an ordinary telephone connection.

First, there is the central office equipment, with its elaborate switchboard and terminal room equipment. Then reaching out from the central offices are the underground wireways, wood and terra cotta ducts (there are over 900 miles of such duct in Pittsburgh's 139 miles of telephone subway) through which run the lead-sheathed cables containing the wires which connect together the many switchboards and bring in the subscribers' circuits to the central offices. Along these underground wireways are the manholes—there are 2000 in the city—in which the cable lengths are spliced together, sometimes 2400 copper wires to a cable, and the smaller lateral cables are led off, still underground, to the more removed business and residence districts. In localities where the development is not great the cables eventually leave the ground and run aerially to junction points where, just as in the more thickly populated parts, the cables are opened up, "tagged" in junction boxes, and the circuits continued by open-wire "drops" to subscribers' premises.

It is probable, though, that the central office is the point of greatest interest, for here enters the personal element—the operator, with all the delicate and complicated apparatus, part manual and part automatic, which is within her control.

A telephone call in a central office, such as Grant, always involves at least two operators—the *A* operator, who receives the call, and the *B* operator, who completes it. This necessitates an *A* board and a *B* board, the former requiring between two and three times more operators' positions.

The Switchboard Apparatus—The A Board—The operator's position, Fig. 2, at the *A* switchboard is, in part, equipped with a row of double-ended cords, two answering jacks for each subscriber's line handled by her and two supervisory lamps for such line. As only subscribers' or "originating" calls are answered here, the equipment before the operator does not include what is known as the "multiple," by which connections are completed to called subscribers. Instead, a "trunk multiple," so called, is installed, and by this the operator

answering a call may secure connections over trunk lines with any other central office from which the called subscriber may be served, as well as to the *B* switchboard of her own central office, through which calls may be completed to subscribers served by the same central office. The two "answering jacks," which are the terminals of a given subscriber's line, take the form of apertures in the switchboard; and as there are two of them for each subscriber's line, separated by an interval of several feet on the switchboard, any one of seven operators may answer the call, whereas on a switchboard of older design equipped with single answering jacks only three operators can make the answering connection. This tends, of course, to facilitate the service, particularly to quicken it when only a portion of the positions at the switchboard are occupied, as during the hours when the traffic load is not heavy, and also prevent calls "piling up" at certain sections of the board.

The B Board is equipped with single cords, each tipped with a plug, the other ends of the cords terminating in the "trunk multiple jacks" of the *A* boards all over the city, certain groups being numbered consecutively and being assigned to each other central office. The *B* operator cannot listen in on any call and cannot talk to subscribers, her dealings being entirely with the *A* operators of her own or other central offices.

Now say that a Grant subscriber takes his telephone receiver off the hook. This is brought to the attention of one of the *A* operators at Grant by a small signal lamp which lights directly above the answering jack at the switchboard at which the subscriber's circuit terminates; this is brought about by the short-circuiting of the line wires, as shown in Fig. 11, causing current to flow through the telephone set on the subscriber's premises, and through the 2000 ohm windings of a small relay at the central office, which, when operated, closes

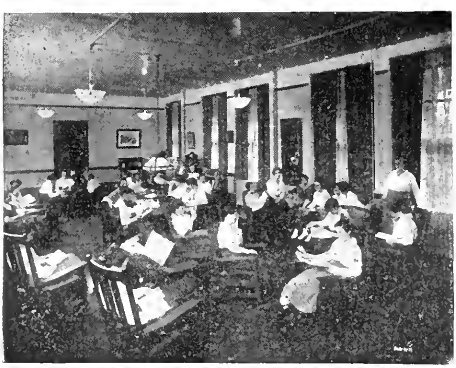


FIG. 7—A TYPICAL REST ROOM
Of which there are two for the women employed in the Grant building.

a local circuit through the signal lamp (0.1 ampere, 24 volts).

The operator answers by inserting in the proper answering jack one of the plugs of any of the connecting cords which may not be in use before her, which extinguishes the signal lamp by cutting off the current supply to the line and at the same time "feeds battery" through the cord circuit to the subscriber's telephone for the purpose of transmission. On being advised as to the exchange and number with which connection is

FIG. 8—ONE OF THE TWO DINING ROOMS IN THE GRANT BUILDING
This is for the women of the clerical force; the operators lunch in a similar room on another floor.

desired, she passes that number along to a *B* operator in the exchange central office called for. To do this she presses one of a group of buttons on the keyboard before her, and by doing so connects her operating telephone set direct with an operator at the *B* switchboard in the called central office. By selecting the proper one of this group of buttons she may thus be connected with an operator at any *B* switchboard in the city. Let us say that a Grant subscriber has called Court 4259. The Grant *A* operator, when connecting with the Court *B* operator, as described, says "Grant 4259," meaning that she, the Grant operator, has a call which is to be connected with Court 4259. Now the Court *B* operator picks up the plug in which terminates a trunk line between Court and Grant and which at the moment is not in use, and, referring to the trunk number associated therewith, says to the Grant operator "36," for example, which is the number of the trunk line by which the connection between the two central offices is to be completed. The Grant operator then takes up the other end of the cord circuit with which she answers the called subscriber and inserts the plug in trunk multiple jack 36 of the group of trunks connecting Grant and Court; while, at the same time, the Court operator, after testing in the subscriber's multiple the line called for to make sure that it is not busy (this is done by touching the tip of the cord plug to the sleeve of the Court 4259 multiple jack, which produces a clicking sound in the operator's head receiver if the line is in use), inserts the plug in the jack and thereby completes the mechanical connection. The ringing of the called person is automatic.

As the test for "busy" is a matter of particular interest to telephone users, it would be well to explain further

that the *B* operator, when testing as above described a line that is in use, always receives a buzz or click each time she touches the cord plug to the sleeve of the answering jack, and also when the contact is broken. This is due to the fact that when a line is busy the sleeves of all jacks of the same line throughout the subscriber's multiple are raised to a potential of 5 volts above the potential of the earth, whereas the tip of the plug is at ground potential; further, if the line is not busy, the sleeve of the jack and the tip of the operator's plug, being of the same potential, result in no busy signal to the operator when contact between them is established.

Should the *B* operator at Court find that the line of the called telephone is busy, instead of inserting the plug of the trunk line in the subscriber's multiple jack, she places it in a switchboard jack which is called the "busy back," and the calling subscriber hears a high-frequency interrupted tone, indicating the busy condition, while the supervisory cord-lamp in front of the *A* operator at Grant flashes, advising of the same condition.

When the Court *B* operator completes the line connection by inserting the cord plug in jack 4259 in the Court subscriber's multiple, the following occurs:—Before it was plugged in, the tip of trunk cord 36 was connected through a small transformer to the Court operator's receiver; the act of plugging in causes a relay to operate which breaks this connection and makes the cord circuit continuous. Simultaneously, a relay, built like a double-pole, double-throw switch, disconnects both talking wires of the trunk circuit and connects the cord to the ringing generator circuit (95 volts, 17 cycles). The cord then conveys this current to the called subscriber's line, 4259.

When the called subscriber's bell is rung, automatically for two-second intervals with four-second rests, continually until he answers or until the call is abandoned, the current on the line to operate the bell is about 27 milliamperes, and when the called subscriber lifts his receiver the impedance of the circuit is so much reduced that a current of about 60 milliamperes flows. This automatically trips a tiny circuit breaker, the winding of which is in series with the generator supply. The operation of the tripping relay (circuit breaker) operates another relay known as a ringing relay (another double-pole, double-throw switch), and this disconnects trunk plug 36 from the ringing current, and in turn connects it with Grant.

At this time there is a talking circuit established between the Grant subscriber and the Court subscriber; but this connection is not direct, for the reason that the Grant subscriber draws his talking current supply from the Grant storage battery, while Court subscriber draws his talking current from the Court battery. This requires the use of two repeating coils, one of which is necessarily in the *A* board cord circuit at Grant, and the other in the *B* board cord circuit at Court.

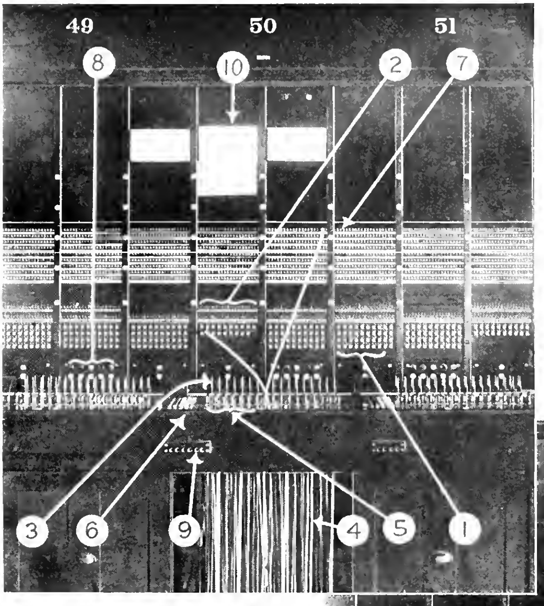
As long as these subscribers continue talking or have their receivers off the hooks the cord circuit signals are all out; there is a signal associated with each of the three cords in use. The process of disconnection is as follows:—When the Grant subscriber replaces the receiver on the hook, a signal lamp associated with the cord circuit used by the Grant *A* operator in establishing the connection lights automatically; when the Court subscriber replaces his receiver, the lamp associated with the plug that at this time is in trunk jack 36 before the Grant operator also lights. The Grant operator, noting both signals, knows that both subscribers have hung up their receivers, and removes the plugs of the cord circuit from both the subscriber's answering jack and from trunk jack 36. If the calling subscriber has individual line measured service, just before the Grant operator removes the plugs she "pegs," i. e., presses a key associated with the cord connected to the Grant number, and thus causes the armature of a message register meter permanently associated with the Grant subscriber's line to pull up. When the armature has traveled far enough to cause the meter wheel of the message register to travel one step, an indicator lamp lights and the operator knows that the call has been registered. The improper registering of connections on which the called party does not answer is eliminated by the operation of the supervisory signal lamps in front of the *A* operator. As previously explained, there are two such signals identified with each cord circuit, one for the originating end and the other for the receiving end of the connection or call. The second signal burns until the called subscriber answers, and when this signal goes out the operator knows that the receiver of the called telephone has been taken off the hook and the conversation begun. The registering of the message is therefore not done until, first, both signal lamps have gone out, indicating that the conversation has begun, and, second, both signals have again lighted up, indicating that the conversation has terminated. The meters are located in plate glass cases in the terminal room and are tested monthly; their construction is such that the only mechanical operating error which can occur is in their failure to register. Recording of messages against party line telephones is handled differently, as meters are not practicable of operation on party line circuits; the recording in such cases is entirely manual, on a small ticket form, which the operator completes similarly upon the termination of the conversation.

Now, continuing the disconnection process, when the cord circuit is removed from the subscriber's answering jack on the Grant board by the *A* operator, the line relay and its associated lamp is switched back into circuit, and when she removes the plug from trunk 36 an associated lamp at Court is lighted and the Court *B* operator takes down the connection, setting the apparatus in position again, so that Court 4259 may receive another call or originate one without delay.

All of these operations are completed very quickly; although they may be made out of the sequence given above, the apparatus will not fail to perform its proper functions nor will the lines become "tied up" or

be rendered inoperative. A complete description of all circuit operations which occur would require a volume of complex drawings, together with an article of many thousand words.

In considering the handling of a call from a Grant subscriber to another Grant subscriber, question will perhaps arise as to why the *A* operator has not within her reach at the switchboard before her a complete Grant subscribers' multiple, that she may thus herself complete all calls from one Grant subscriber to another, as is the practice in smaller cities where all subscribers' lines are served from one switchboard. The explanation is that in a central office such as Grant, approximately 75 percent of the originating calls are for subscribers served by other central office switchboards; and whereas that high percentage of the originating calls must be trunked, there is distinct economy to the company and no resulting inconvenience or delay to subscribers if the subscribers' multiple is eliminated from the *A* switchboard and calls to Grant subscribers from Grant subscribers are trunked through the Grant *B* switchboard, just as are trunked such calls from subscribers in Court or other central offices. Not only the annual charges are saved on the great investment that would be involved should the subscribers' multiple be extended from the Grant *B* board to the *A* board as well, but by its elimination from the *A* board the line capacity of the switchboard unit is greatly increased. An *A* board with subscribers' multiple is—with the presence of an extensive trunk jack section—generally limited to about 5000 lines, by reason of the natural limits of reach of an average operator. But by confining the multiple to the *B* board alone, from which the trunk answering jacks are of course eliminated, the multiple can be conveniently extended to embrace over 10 000 lines.



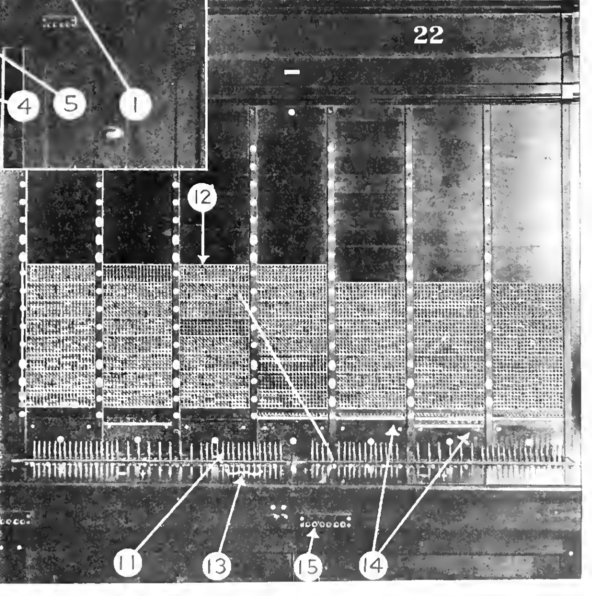


FIG. 9 (above)—AN "A" SWITCHBOARD SECTION

FIG. 10 (at right)—A "B" SWITCHBOARD SECTION

1—A group of subscribers' answering jacks with associated line signals. *2*—A group of "ancillary" jacks, which duplicate a group of answering jacks at a nearby position and make it possible for the operator here to assist in the handling of calls at that other position when the volume of traffic is very heavy or when not all positions are occupied. *3*—Plugs of the double-ended cord circuits. *4*—Flexible portion of cord circuits exposed. *5*—Listening keys and supervisory signals. *6*—Call circuit buttons, by which connections are had with *B* operators. *7*—Trunk multiple jacks. *8*—Pilot and supervision signals. *9*—Sockets at which the operator connects her operating telephone set to the switchboard. *10*—Instruction and special information cards. *11*—Trunk circuit cords, by which the *B* operator completes through the subscribers' multiple the connection which has been made to the trunk circuit by the *A* operator. *12*—The subscribers' multiple; here before the B operator are the terminals of 5300 lines, with capacity for growth to 10 500, to any of which she may complete a connection. *13*—Supervisory signals. *14*—Trouble jacks, and the "busy back" to which the connection is made when the line called for is busy. *15*—Connection socket for operator's telephone.

HANDLING OF TOLL AND LONG-DISTANCE CALLS

The handling of a toll or long-distance call is of further interest: in describing the operations, practi-

cally all reference to the apparatus may well be eliminated.

First, the Grant subscriber, taking his telephone receiver from the hook, asks for "Long Distance," and the *A* operator inserts in any of a number of switchboard trunk jacks marked "Long Distance" the other plug of the cord circuit with which she has answered the subscriber, and rings. This lights a signal lamp on a switchboard at the long-distance office known as the recording board; the operators on this board are known as recording operators, and do not complete any connections, as none of the subscribers' lines or toll lines terminate in the board before them. The calling subscriber then gives to the recording operator the necessary information regarding the connection desired, and the recording operator originates a "ticket"—a small piece of paper on which is put down the details of the call. After the customary "Thank you, the operator will call you," she drops the ticket into a pneumatic tube (vacuum system, 1.4 inch of mercury) and the ticket is carried through the tube to one of the distributing operators, who notes the terminating point and forwards the ticket to the proper line or toll operator handling calls to that point; in front of the distributing operators are tubes opening to the various line boards, and by one of these tubes the ticket is conveyed to the ticket boxes on the toll switchboard, where one of the toll operators immediately picks it up. The toll operator then presses a call-wire key leading to the *B* operator's position at the central office where the toll call originated, and asks the *B* operator to assign a trunk for later connection with this subscriber's number. The *B* operator assigns a trunk and the toll operator holds that trunk by placing a plug in the proper trunk jack, which condition is maintained while she selects an idle toll line to the called point and secures the attendance of the called person at the telephone.

The toll operator, when the called person is at the telephone at the distant point, rings manually the person originating the call and introduces the calling and called persons. Then, at once, she places the toll ticket in a calculagraph or printing-recording clock which, upon the pressing of a lever, registers the time at which the conversation begins; later, when the disconnection signals automatically indicate the hanging up of receivers, the pressing of another lever of the calculagraph registers the elapsed time in minutes and quarter minutes. Removing the ticket, the line operator then drops it into an open ticket tube and it is returned to the filing operator; on the following day the ticket is forwarded to the accounting department, where an entry of the call, together with the amount of the charge, is made on the subscriber's ledger page.

In the handling of toll or long-distance connections there are involved, at the point at which the call originates, an *A* operator, a recording operator, a distributing operator, a line or toll operator, a *B* operator and a filing operator; at the terminating point there are involved a line operator and a *B* operator. Thus the services of eight operators are required to handle a toll call on which no complications (such as must be necessitated for the arrangement of messenger service, etc.) arise. And, just as a matter of interest, on a 65 cent call from Pittsburgh to Cleveland, something like $35 000 worth of plant is used, considering only that equipment which is directly involved in the call.

DETERMINATION OF TRAFFIC LOADS AND OPERATING REQUIREMENTS

Were it not for the carrying charges—including interest, depreciation, taxes, etc., on equipment and buildings—the initial installation of central office equipment would tally as closely with the ultimate requirement as existing switchboard capacities permit, which, at the present stage of the art, is a board sufficient to handle approximately 10 500 subscribers' lines. However, those expense factors make it economical to install only sufficient equipment to last through a given period of years, which period is determined by the weighing of carrying-charge items against the cost of engineering and labor to make the supplemental installation. Having determined the length of this period and area to be served by a particular central office, it is necessary to estimate the requirements essential to the giving of the

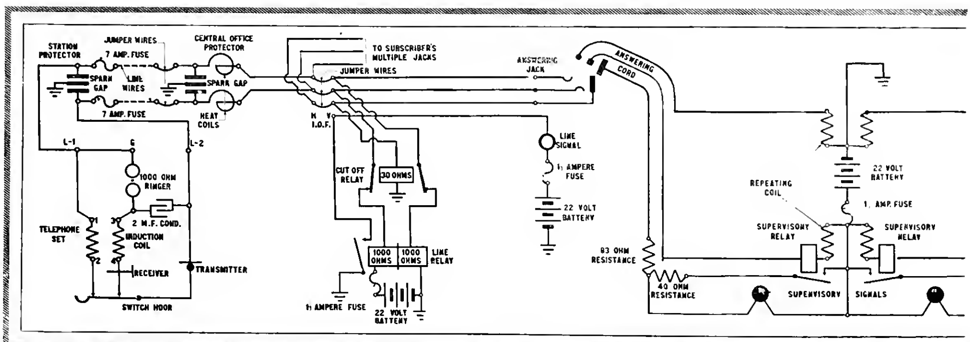


FIG. 11—ABOVE, AND CONTINUED ON THE FACING PAGE, IS A DIAGRAMMATIC REPRESENTATION OF THE CIRCUIT EQUIPMENT INVOLVED IN THE COMPLETION OF THE MOST SIMPLE TELEPHONE CONNECTION, AS IN A CITY WITH BUT ONE CENTRAL OFFICE

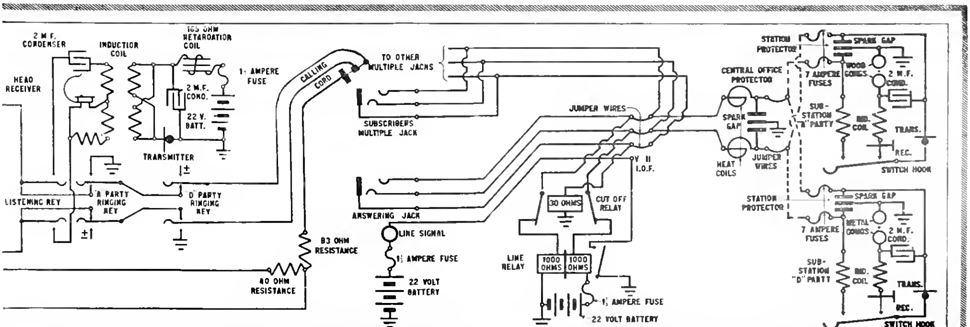
best grade of service to the public in the most economical manner.

Now, for a given period under observation there is determined the approximate changing population figures within the central office area, the anticipated classes of business and residence expansion, the expected telephone development thereunder, and the variety of grades of service that will be in demand. From this, of course, the number and kind of subscribers' lines and stations (telephones) which will be connected to the central office during and at the termination of the period are determined. Further, an estimate of the volume of traffic (number of calls) originating from and incoming to the estimated stations is made. Having reached these several approximations, the number of operators' positions, toll lines and trunk lines for connections to other offices are calculated, based on the best traffic data obtainable; similarly the number of subscribers' multiples and answering jacks are determined, and the arrangement thereof to afford the most efficient manual operation.

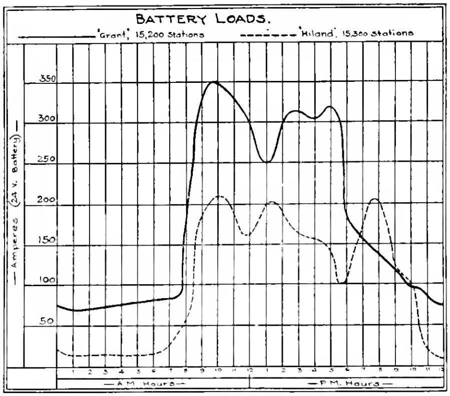
From all of the data thus obtained, and other estimated requirements under certain miscellaneous equipment items, specifications and drawings are prepared and forwarded to the factory for manufacture and installation. So the initial installation of equipment is made and from time to time added to until the ultimate is reached, when another unit is planned.

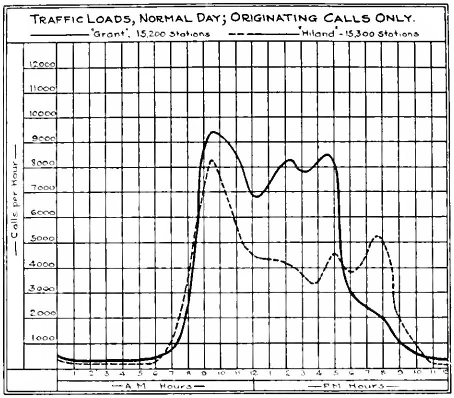
In order that the company may have a sufficient number of operators on duty at all seasons of the year and at different times of the day, various studies are made to determine the amount of traffic from day to day and from hour to hour. On account of the many different kinds of calls that are handled and the amount of work varying for each class of calls, it is necessary to express the amount of work involved in those classes in terms of units of labor, the unit being common for all classes. The unit used is "local call." This is the type of connection which is completed in an office such as Hiland when one Hiland subscriber calls another Hiland subscriber and the answering operator completes the connection through the subscriber's multiple in front of her, with no trunking of the call to a *B* operator either at her own central office or at another one in the city. This unit is used because it is the simplest class of call handled.

First, a "standard load" is determined, this being the number of units that an average operator can handle for an hour continuously and give a thoroughly satisfactory grade of service; it is, of course, based on the condition of all switchboard positions being occupied, for during hours of the day when there is less traffic and only a portion of the switchboard positions are occupied, each operator is expected to handle a smaller number of units, as the number of incoming lines assigned to her is greater and, although the manual movements in handling cord circuits do not increase in number, the reach or extent of those movements is increased. Calls involving trunking to other operators or central offices, as well as calls involving ticketing of the traffic for purposes of billing, etc., require more than one unit of labor each. In order properly to estimate the traffic at each central office for each hour of the day, it is necessary to maintain several kinds of records. To determine the total volume of traffic in a given central office a continuous record is kept each day in the year, each operator on making a "peg count" (by the manual pressing of a button on the switchboard in front of her whenever a call is originated) during certain hours of the day; by the application of averages and unit factors the total traffic volume may be determined from these peg counts with sufficient accuracy, as the count is used only for the purpose of general traffic studies. Further peg count records are kept on a monthly basis (again by manual pegging) during certain hours of the day to determine the distribution of the traffic by hours, while other supplemental records are kept, on a quarterly basis, for the purpose of determining the kinds of calls handled. The supplementary records are summarized and percentages obtained of the total traffic handled on the days on which the supplementary counts are taken. These percentages are applied to the continuous records, and there results a very accurate estimate of the amount of operating work performed at each central office and for each hour of the day.



TO SHOW SIMILARLY THE EQUIPMENT INVOLVED IN THE ESTABLISHMENT OF A CONNECTION BETWEEN A GRANT AND A HILAND SUBSCRIBER, OR EVEN BETWEEN TWO GRANT SUBSCRIBERS, WOULD REQUIRE A MUCH ENLARGED DIAGRAM





FIGS. 12 and 13—CURVES INDICATING NORMAL BATTERY LOADS AND TELEPHONE TRAFFIC VOLUMES IN A TYPICAL BUSINESS CENTRAL OFFICE AREA (GRANT) AND A TYPICAL RESIDENCE CENTRAL OFFICE (HILAND)

Having determined from the various records the volume and classes of calls handled for each hour of the day, the proper co-efficient is applied, reducing the calls to units of work. The number of operators required for each hour is then obtained from these units. The hours of duty for each operator are so arranged as to bring to the switchboard a varying number of operators from hour to hour during the day, not only in order always to have a sufficient number to handle the traffic properly, but also in order not to provide more operators than are necessary. The tour of duty of a day operator includes eight hours of work, which are divided into two periods of approximately four hours each, and there is always at least one hour allowed for lunch between these hours. In the middle of each period a ten-minute rest is given to each operator, and she may leave the switchboard at any time for any reason upon request to her supervisor. Operators who work all or a portion of their time in the evenings are required to work but seven hours per day, and the evening operators do not work later than 10:30 P. M. in Pittsburgh, in order that the hour of their leaving the central office may not be too late for them to return safely to their homes. Wherever practicable, operators are assigned to central offices nearest their residences. The night operators come on duty about ten o'clock and leave at seven o'clock next morning, with rest and lunch hours during the night; as the night traffic is heaviest between 10 P. M. and midnight, the number of operators on night work is determined by the volume of traffic between those two hours; for the remainder of their tour of duty the night operators not required at the switchboard are engaged in clerical work.

The curves shown in Figs. 12 and 13 represent the traffic load during an average 24 hour period for a typical business and a typical residence central office. These diagrams illustrate what tremendous variation in calls there is from hour to hour, and give some idea of the very careful planning that is necessary in order to have enough operators for certain busy hours and not too many for the slack hours of the afternoon and evening. In addition to the regular force, certain auxiliary or relief operators are employed to balance the number of absences and resignations, as well as daily vacancies in the force due to operators being excused by reason of their having worked on Sunday. A record of absentees is kept at each office; sufficient absentee-relief operators are provided to cover a condition somewhat between an average and a maximum. A record of resignations is also kept and, in order that trained operators may be available when resignations occur, a resignation reserve is employed; to permit operators who work on Sunday to be excused some other day of the week, there is a force of Sunday relief operators, one of which force will provide during the calendar week a relief for six operators who have worked on Sunday.

As might be supposed, the problem of training operators to fill the permanent vacancies that necessarily occur continually in so large a force is no mean one, and an operators' school is in continuous session. Thirty years ago, when the telephone pioneers were just setting forth on their long path of experience and progress, bright young boys of fifteen or sixteen were engaged to operate the crude contrivances that were then called switchboards; but their outrageous language and manners soon pointed to the expediency of employing young women operators. Telephone operating means more than the self-control and voice modulation that we have come to know so well. Public requirement demands a maximum of speed and efficiency, with a minimum of error. So came to be established the operators' school. Here each embryo operator must first show herself to be well poised, gracious and alert. The telephone "language," the voice inflections and finally the intricacies of the apparatus itself are individually taught and mastered; after the "theory" there is practice—at a real switchboard, but one without communication to the outside world. The "subscribers" are the instructresses, and the student operators here train their fingers and minds by handling "dummy" calls of the hundreds of the varied sort that will later come to her. Though each student operator is paid throughout the several

weeks of her instruction, she does not take a position at a central office switchboard until she proves her efficiency at the school.

MAINTENANCE AND TROUBLE TESTS

A synoposis only of the maintenance and testing work is possible in a few words. Briefly, a subscriber's circuit is divided into three parts,—the inside (central office apparatus), the line (which may be underground, aerial cable, aerial wire, or a combination of all), and the substation, which is the apparatus on the subscriber's premises. Every subscriber's line is tested six nights a week; and as this test is made successively from different positions at the switchboard each night, every jack in the switchboard is tested several times a month, depending on the size of the multiple. By means of these nightly (except Saturday) tests, many minor troubles are discovered, and it is not unusual for the trouble man to call at subscribers' premises before the latter are aware that their service is in any way affected.

Another test which is made on those subscribers' lines which are in exchanges equipped with automatic ringing is the "insulation break-down" test, which is made monthly and also immediately after electrical storms. The insulation test consists of a 200 volt battery in series with a high-resistance relay, which indicates the failure of insulation by the lighting of small tungsten lamps. One portion of the standard protection apparatus consists of open space cut-outs which normally break down at 350 volts. This is accomplished by separating two small carbon blocks by mica 0.0055 inch in thickness. During electrical storms and due to damp conditions, the break-down insulation between these two blocks decreases, and when it reaches a value which will break down at about 150 volts the ringing generator current jumps the air gap and operates the tripping relay of the *B* switchboard cord-circuit, previously described. This results in the failure of the subscriber's bell to ring. The test above described is also applied to all lines on which trouble is reported and on which trouble and routine inspections are made, thus safeguarding the service to the highest possible degree.

Each cord-circuit is tested every week as to its ringing, signaling and listening conditions, as a guard against cords that are beginning to break down electrically or mechanically. As an example of how finely some tests are made, a brief description of the three-cord supervision tests is given.

TABLE I—A FEW FACTS AND STATISTICS AS OF JULY 1, 1916

THE NEW GRANT BUILDING		
Construction Work Begun		March 21, 1914
Building Occupied		June 1, 1915
Central Office Installation Begun		April 24, 1915
Length of Building		180 Feet
Width of Building		58 Feet
Height above Ground		157 Feet
Depth below Ground		26 Feet
Available Floor Space		62 000 Sq. Ft.
Weight of Steel in Structure		2740 Tons
Approx. Cost of Bldg. and Equipment		$1 420 000
	Operators	Employes
Grant Bldg. (complete)	646	1426
Pittsburgh	1537	2671
The Central District Telephone Co	3347	5375
The Bell System	85 000	165 000
TELEPHONES		
Grant Bldg. (complete)		307
Grant Central Office Area		15 200
Pittsburgh		85 000
The Central District Tel. Co.		200 000
The Bell System		9 700 000
DAILY VOLUME OF TELEPHONE CALLS		
Grant Central Office *		75 000
Information, Toll and Long Distance		13 400
Pittsburgh		405 000
The Central District Tel. Co.		671 000
The Bell System		32 000 000

*Originating calls only.

The operator first tests by placing the cord-circuit in a switchboard jack marked "Traffic Cord Test;" there is a shunt resistance constantly in circuit of 10 000 ohms, which is to cause the armature of the relay to stick if it is set too closely. Then, by means of an automatic device, a resistance of about 500 ohms is connected across the test jack 120 times a minute, which gives, in a much intensified way, the same operation as a subscriber working his hook up and down on a line of high-loop resistance. Note the margins of safety; the leakage current through 10 000 ohms is ten times that normally met with in practice, for the standard loop insulation in dry weather is 300 000 ohms and for wet weather is 100 000 ohms insulation resistance; 500 ohms is an artificial subscriber's loop —the average is 200 ohms, with a maximum of 300; the receiver hook (imitated) is operated one hundred times a minute—double the normal speed at which a subscriber operates the hook when recalling the operator and three or four times as fast as the hook should be operated if the operator's attention is to be secured most speedily.

It is customary each week for one of the night men in the "terminal room" of the central office to test every relay in the "routine testing jack," which is twice as severe a test as the one previously mentioned. The lamp must flash 120 times a minute under the following conditions:—The test jack is short-circuited for three seconds and then shunted with 1153 ohms, and the leakage shunt is reduced to 5431 ohms. When a relay requires adjustment, the fineness of the test is again almost doubled.

Without going further into the detail tests made in the central offices, it may be said that special routine tests have been devised and equipment installed for testing every piece of apparatus in the central office with sufficient frequency to anticipate practically all trouble before the service is affected. The periodicity of these tests varies from daily to annually according to the importance and delicacy of the apparatus in the circuit.

In order to determine how frequently tests should be made, data was collected for several years, showing

the amount of trouble experienced for each type of relay in each class of circuit. In order to determine the best type of test circuit to be used many studies were made to ascertain the most severe condition under which the apparatus would be required to operate in practice, and then the test circuits were so designed to allow a very wide margin of safety. When a subscriber calls to report line or instrument trouble of an unknown sort he is connected with the "trouble operator." Upon learning the number of the telephone affected, the trouble operator removes the proper card from a numerical file of subscribers and records thereon the date and time and, in code, the nature of the trouble. If the subscriber's report is that he "can't hear well," the operator enters "C.H." and passes the card along to the test-man. The latter "orders up the line," i. e., the *B* operator connects it to his desk and he tests the line for noise and insulation trouble and rings the subscriber, thus effecting a break-down insulation test. Next, he switches into the circuit a 20 mile artificial cable and attempts a conversation. If the result of this test leaves any doubt as to the nature of the trouble, an inspector is sent out, and when the trouble is found and corrected, the card is returned to its proper place in file.

In case the subscriber's report is that the "bell doesn't ring" ("B.D.R." is the customary code therefor), the 200 volt break-down test is applied; if "can't be heard" ("C.B.H." is the code) is reported, or "can't get central" ("C.G.C."), particular tests are used according to the trouble indicated by the report.

Permanent signals (the code is "P.S.") resulting from subscribers leaving their receivers off the hook or pushing books and other obstructions under the receiver so as to lift the receiver hook, causes the greatest amount of trouble, about 100 cases of this sort being reported every day in the Grant central office alone. The routine trouble card used by the test men contains space for 45 trouble entries, but so frequently do permanent signals result on some lines that the cards therefor last only about a month.

About 500 trouble inspections are made daily—in Pittsburgh and its suburbs—of subscribers' telephones, a total of 100 000 telephones, or an average of 1.5 visits per station per year.

In addition to actual trouble inspections, special visits are made even when no trouble is reported, merely for testing purposes, and many service interruptions are accordingly prevented. Frequently telephones are slightly in trouble for long periods before the subscribers make report thereof, and it is particularly with this class that the special inspections are valuable; the great number of parts replaced and the frequency of apparatus adjustments is evidence that the practice is warranted where a high standard of service is to be maintained, especially at business stations where the rate of calling is high and usage of the apparatus sometimes rather rough.

In the case of toll line maintenance, routine tests are made on all toll circuits daily—ringing, listening, talking and volt-meter tests. Monthly an insulation test is made on each individual wire and the insulation in meg-ohms is ascertained per mile-wire. Quarterly toll-line tests are made for noise, both by day and by night. Likewise, tests are made semi-annually with the Wheatstone bridge to check the ohmic balance, i. e., the similarity of the resistance of the same gauge toll line wires between certain points, while annual tests are made to determine the amount of cross-talk existing between different circuits on the same pole line; cross-talk is the very faint talk which is on occasions heard when a conversation is held over a long stretch of wire, and is often a most elusive leakage to deal with.

LIGHTING AND POWER LOADS

Lighting and power loads for telephone buildings are subjects of constant study among electrical as well as telephone companies. The lighting load, while practically *nil* during the day, is almost constant throughout the night. The power load usually starts about 8:30 A. M. and, with little variation, is over at 5 P. M. Therefore only in the late afternoon is any one of the supply company's peaks encountered.

For the Grant building there are installed four 100 kw transformers in a special vault, in accordance with the city's regulations. The telephone companies have at some points undertaken to make their own power, either by gas engine or by steam; but as a rule this has usually been supplanted by central station power later on. A few years ago many exchanges of the Pittsburgh division were operated by gas engine plants, but these have practically all been replaced; the absence of noise, reduction of fire hazard and cost of attendance are all factors influencing the purchase of power from outside sources whenever practicable.

Altogether, the study of telephone equipment and operation is one of particular interest, not only to the engineering mind, but also to that of any one interested in business economics and efficiency. The telephone art is a new one; for, despite the forty years of history that lie behind, the road stretches endlessly ahead. There are almost daily presented for solution problems that are quite new—problems involving original research and study along paths in which new pioneering must be done. The realization of transcontinental telephony and across-the-ocean speech by wireless are but episodes. For though they evidence the unusual accomplishment of the 600 scientists and specialists which makes up the engineering corps of the Bell system, yet, when all is said and done, they serve but to point the way toward that ultimate realization which was spoken of by Chief Engineer J. J. Carty, of the American Telephone and Telegraph Company, when, in a recent paper before the Franklin Institute, he said:—"No one can tell how far away are the limits of the telephone art. I am convinced that they will not be found on this earth; for I firmly believe that some day we will build up a world telephone system, making necessary to all people the use of a common language or a common understanding of languages which will join all of the people of the earth into one brotherhood."

Reversing Roll Motors in Steel Mills

W. R. Runner
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Westinghouse Electric & Mfg. Company

A WELL-KNOWN characteristic of the American steel mill operator is the rapidity with which he adopts any new device which has proven itself well suited to his work. The rapid adoption of the electrically-driven reversing mill is one of the most striking examples of this characteristic. One and one-half years ago there were two electrically-driven reversing mills operating in the United States, and one in Canada, with two more under construction, while at the present time 15 mills are either in operation or being constructed.

This rapid spread of electrically-driven reversing mills is due largely to:—

1—Economy of operation.
2—Reliability of operation.
3—Facilitating methods of mill layouts.

The steel which has been converted from the crude pig iron, either by the open-hearth or the Bessemer process, is cast into ingots weighing from 4000 to 8000 pounds, or larger, depending on the size of the mill. These ingots are next placed in furnaces, known as soaking pits, where they are left until they attain a uniform temperature of approximately 2200 degrees F. They are then ready for the rolling mill.

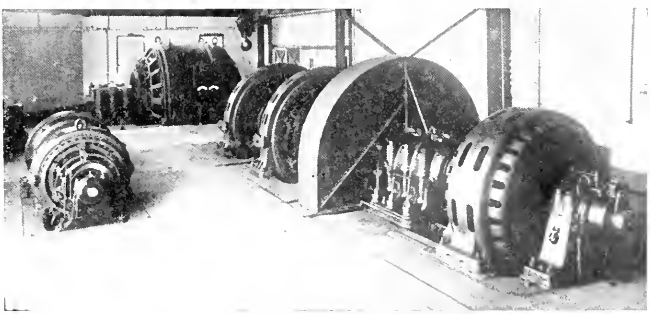

FIG. 1—REVERSING MILL DRIVE
Steel Company of Canada.

The layout of a mill, designed for rolling sheet bar, this being steel bars approximately 0.5 by 8 inches, suitable for re-rolling into sheets, is shown in Fig. 3. The ingot, which is about 18 by 20 by 50 inches, is placed on the roller table at *A* and is rolled down to the mill. This roller table consists of a number of cast-steel rollers driven by a small motor, as shown in the immediate foreground of Fig. 2. The bloomer or main rolls are the ones which are grooved, being driven through spindles which are connected to two large pinions with a one to one ratio so that both rolls turn at the same speed. The upper roll is moved up and down by means of a small motor mounted on the top of the mill, the distance between the rolls being indicated by dials on the top of the mill.

The ingot is passed through the bloomer rolls 19 or 21 times, the upper roll being lowered a little at each pass. The metal is frequently turned through an angle of 90 degrees by an electrically-operated device known as the manipulator; this turning enables the operator to keep the cross-section of the metal approximately square. This gradually reduces the cross-section of the ingot, and increases its length, until it is 8 inches wide, 3 inches thick and approximately 62 feet long. This is known as the bloom. This bloom is then sent to the shear by a long roller table and is cut into several pieces, which are then sent through the various rolls of the bar mill, finally passing through the bullhead mill, this giving the planishing pass. The bar now has a cross-section of one-half inch by eight inches and is ready to be cut into commercial lengths and shipped to the sheet mill. In other mills the bloom may be rolled to various shapes and sizes, such as I beams, angles, etc., for the merchant trade, or it may be cut to short lengths, known as billets, for re-rolling in bar or rod mills. The treatment in the bloomer remains practically the same, the size of the bloom being determined by the final product to which it will be rolled.

The electric reversing-mill drive* of the type shown in Fig. 1 consists of a reversing motor and a flywheel motor-generator set, together with the necessary exciters and control equipment. The flywheel motor-generator set consists of a wound-rotor induction motor driving a flywheel and two direct-current generators, these generators supplying the power for the double-unit reversing motor. In this installation the reversing motor was built in two units, mounted on the same shaft, to reduce the inertia of moving parts.

A schematic diagram of connections for a reversing-mill drive using a single-unit motor is shown in Fig. 4. The same general scheme of connections is used with the double-unit set, except that the four direct-current machines are in series. The motors and generators are alternated, thus placing a motor in each circuit between the two generators. The induction motor *ACM* receives its power from the main switchboard through a series transformer, the secondary of which is connected

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*See "Electric Drive for Reversing Rolling Mills," by Messrs. Wilfred Sykes and D. Hall, *Proceedings A.I.E.E.*, June, '16, p. 739, and "Electrically-Driven Reversing Mills," by Mr. Wilfred Sykes, *Proceedings A.I.E.E.*, June, '11, p. 1285.

to the torque motor on the slip regulator *SR*. The direct-current generator of the set is connected directly to the armature of the reversing motor, the circuit passing directly through the field of the exciter *ScE*, for supplying the series excitation. Two small exciters *SE* and *ScE*, driven by *SACM*, supply the field current for both

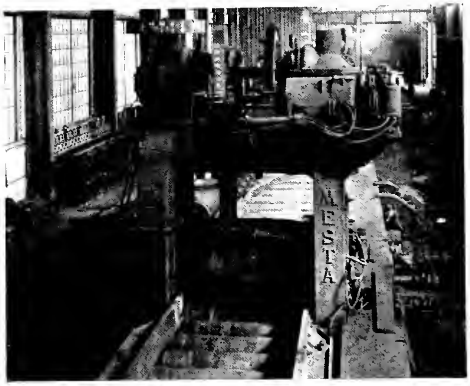

FIG. 2—REVERSING BLOOM MILL
Driven by 8000 hp motor, at the Central Steel Company's mill at Massillon, O.

the mill motor and the generator. The type of exciter set used consists of a shunt exciter, driving motor and series exciter, as shown in Fig. 5. The heavy bar field winding, which carries the reversing motor armature current, may be seen on the series exciter.

The generator field is excited from the shunt exciter through the necessary control to vary the exciting current from zero to a maximum in either direction. The motor field winding is made up of two separate sets of coils. One winding receives its excitation from the shunt exciter and is known as the constant potential field, while the other winding is supplied by the series exciter and is known as the variable potential field. Since the series exciter has its field in series with the main circuit between the motor and the generator, its voltage, and therefore the current in the variable potential field, will be proportional to the current flowing between the machines. This gives the reversing motor the characteristics of a compound motor without the necessity of reversing the heavy armature currents at

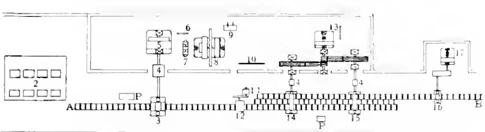

FIG. 3—GENERAL LAYOUT OF ROLLING MILL

2—Soaking pits; *3*—Blooming mill; *4*—Pinion stands; *5*—Reversing motor; *6*—Circuit breaker panel; *7*—Exciter set; *8*—Equalizer set for reversing motor; *9*—Slip regulator; *10*—Switchboard; *11*—Shear motor; *12*—Bloom shear; *13*—Bar mill motor and control with rope drive; *14*—First stand bar mill; *15*—Second stand bar mill; *16*—Bullhead stand bar mill; *17*—Bullhead motor with reduction gear; *P*—Operators' pulpits; *A*—Point where ingot enters mill; *B*—Point where finished product leaves mill.

every reversal of rotation, as would be necessary with the usual type of compound machine. A small magnetic switch reverses the variable potential field and, as the current is less than 100 amperes, this method of compounding has many advantages over the usual type, where it would be necessary to reverse a circuit carrying as high as 10 000 amperes.

The reversing motor is controlled from the mill pulpit by means of a small master controller, which actuates the magnetic switches constituting the field control for the equipment. Relays are provided to prevent careless operators from mistreating the apparatus, and the entire equipment is so designed as to give reliable operation under the most severe conditions.

The general scheme of operation is outlined as follows:—With the motor-generator set and the exciter set running full speed, and with the master controller in the *off* position, the reversing motor is standing with full excitation on its constant potential field. When the master controller is moved in one direction or the other

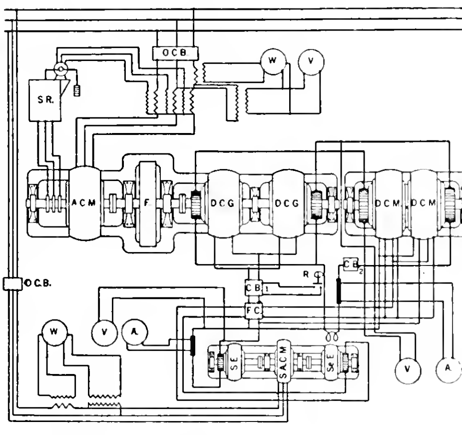

FIG. 4—SCHEMATIC DIAGRAM OF CONNECTIONS OF A LARGE REVERSING MILL DRIVE

OCB—Oil circuit breaker with no-voltage and overload trip; *SR*—Automatic liquid slip regulator; *ACM*—Alternating-current wound rotor induction motor; *DCG*—Direct-current separately excited generators; *DCM*—Direct-current separately excited roll motors; *CB*—Circuit breakers, *1*—generator field, *2*—main circuit; *R*—Relay for operating circuit breaker in generator field; *FC*—Field controller; *SE*—Shunt exciter for generator and roll motor fields; *ScE*—Roll motor exciter, the field of which is separately excited by the main direct-current circuit; *SACM*—Alternating-current squirrel-cage induction motor; *V*—Voltmeter; *A*—Ammeter; *W*—Wattmeter; *F*—Flywheel.

the motor will rotate at a speed and in a direction depending upon the position of the controller handle. The motor speed is controlled by varying the generator voltage up to full voltage on the generator, speeds above this being obtained by weakening the motor field. As the load comes on the motor the voltage on the series exciter increases, due to the increased current in the main circuit. This in turn increases the field strength of the roll motor, causing it to slow down, thus decreasing the strain and shock on the mechanical parts of the motor

and mill. The increased field strength also increases the torque available for handling excessive loads due to cold metal in the rolls or to excessive reductions.

The roll motor is stopped by dynamic braking. When the controller handle is moved towards the *off* position the generator field is weakened, causing the power to flow towards the generator. The generator then reverses its function, now acting as a motor, increasing the speed of the set and storing energy in the flywheel. In this way a large part of the energy used to accelerate the motor is reclaimed, tests showing that as high as 70 percent of the accelerating energy is returned to the set for use during the next pass. This regenerative action brings the motor very quickly to rest, making the operation of the mill very fast.

Since the load on the reversing motor during the pass may be from three to five times the average load, this peak on some equipments often being as high as 15 000 hp, it will be seen that it is absolutely necessary to provide some means of equalizing this load. This is the function of the fly-wheel on the motor-generator set. As the load comes on, the torque motor, being operated

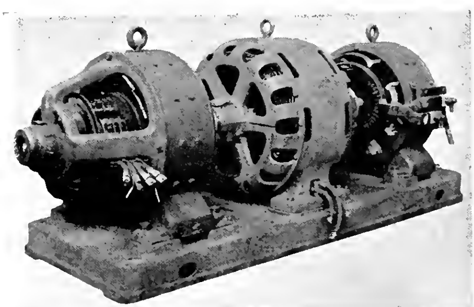

FIG. 5—EXCITER SET

from the series transformer in the primary circuit of the driving motor on the set, tends to separate the electrodes of the slip regulator.* When the load increases beyond the setting of the regulator the electrodes separate, inserting resistance in the secondary of the induction motor. This causes the motor-generator set to slow down, permitting the flywheel to give up a part of its energy, and thus take the peak loads without drawing excessive loads from the line. If the regulator is set to operate at the average load on the mill, the motor will operate at this load continuously, the flywheel giving up energy when the mill load is in excess of this average, and absorbing energy when the mill load is below the average. This ideal condition is very closely approximated in actual service.

The reversing motor is of special design and is extremely rugged, both mechanically and electrically, to withstand the severe strains of steel mill service. Fig. 6 shows a 15 000 hp double-unit motor having a speed range of 0 to 120 r.p.m. A single-unit motor rated at 8000 hp, having a speed range up to 120 r.p.m. and the equalizer set for this motor are shown in Fig. 7. These motors are very substantially built and all parts subject to shock or strain are of steel, the frame and spider being steel castings of such design that the maximum

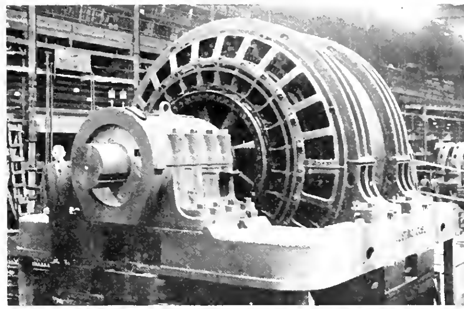

FIG. 6—15 000 HP DOUBLE-UNIT REVERSING MOTOR
United Steel Company.

strength is secured without making the motor unduly heavy and unwieldy. The pedestal supporting the rear end of the armature is also of cast-steel, as this pedestal must withstand the thrust in event of a spindle breaking. The stationary half of the thrust bearing used is shown in Fig. 6, the hub of the coupling being surfaced to form the rotating half of the bearing.

As the load on a reversing motor fluctuates very rapidly, successive peaks being only two to three seconds apart during the first few passes, it is necessary to make special provision to secure sparkless commutation. On the ordinary commutating-pole, direct-current motor the sparking which accompanies severe load fluctuations is caused by the shifting of the field due to the changing of the armature magnetization. To overcome this a wind-

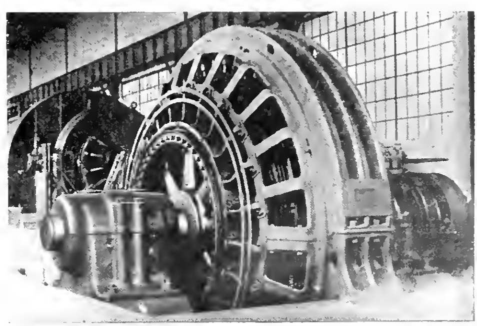

FIG. 7—8000 HP SINGLE-UNIT REVERSING MOTOR
Installed at the mill of the Central Steel Company, Massillon, O.

ing, known as the compensating winding,† is added. This winding, which is in series with the armature circuit, is embedded in the pole faces of the machine, and

*See "Control of Induction Motors for Rolling Mill Drive," by Messrs. Wilfred Sykes and G. E. Stoltz, in the JOURNAL for Dec., '14, p. 709.

†See "The Compensated Generator," by Mr. David Hall, in the JOURNAL for Aug., '16, p. 378.

is so proportioned that it completely neutralizes the field produced by the currents in the armature. This effectively prevents all shifting of the field, and consequently insures sparkless commutation throughout the most severe load fluctuations. A single-unit reversing motor

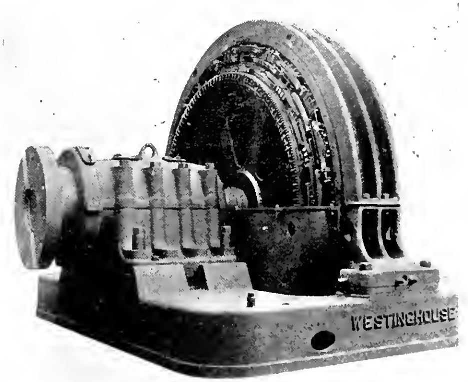

FIG. 8—8000 HP REVERSING MOTOR
Showing compensating windings.

with one-half of the rear-end bell removed, showing the type of compensating winding used, is shown in Fig. 8.

The equalizer set, consisting of a wound-secondary induction motor, a flywheel and one or more direct-current generators, is mounted upon a large cast-iron bedplate, which is made in sections to facilitate shipment and erection, the sections being firmly bolted together, thus insuring the alignment of the various machines. An equalizer set for use with a 12 000 hp double-unit reversing motor is shown in Fig. 9 assembled without the flywheel. The flywheel is to be mounted on the short shaft between the two large bearings. This shaft is coupled to the motor and generator shafts, thus making it possible to dismantle any machine without disturbing the heavy flywheel which, on this set, weighs approximately 90 000 pounds. After assembly, the flywheel is covered by a sheet-steel case, thus reducing the windage losses and making accidental contact with the running wheel impossible. The generators, since they must commutate the same fluctuating loads as the reversing motor, are also of the commutating-pole, compensated type described under the reversing motor. With this exception the set construction is along the standard lines of design for moderate-speed machines.

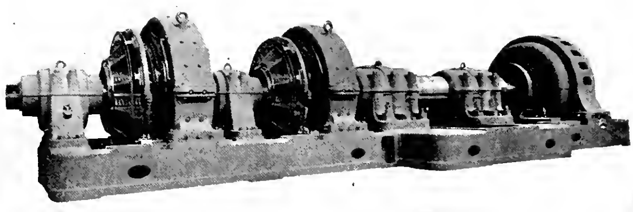

FIG. 9—EQUALIZER SET
For 12 000 hp double-unit reversing motor.

Since the induction motor supplies only the average load throughout the cycle its rating is much lower than that of the generators. For example, on a given equipment having motors rated at 12 000 hp maximum the generators might have a root mean square rating of 5000 kw, and the driving motor a rating of 3000 hp. The ratios of the driving motor capacity and the generator capacity to the maximum rating of the reversing motor

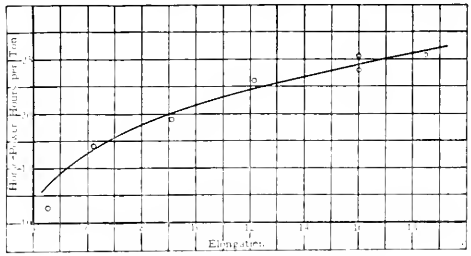

FIG. 10—POWER REQUIRED TO ROLL STEEL
Using electric reversing motor drive.

depend entirely upon the class of rolling and must be computed for each proposition.

The economy of the electric drive is clearly shown in Figs. 10, 11 and 12. The horse-power-hours per ton of steel rolled, plotted against the number of times the steel is elongated in the mill, is shown in Fig. 10, which shows the input to the driving motor of the set, and includes all losses. The economy curve of a 5000 kw turbo-generator set giving pounds of steam consumed per horse-power-hour output, including all losses and steam for auxiliary drive, is shown in Fig. 11. It will be seen from Fig. 10 that, at ten elongations, 21 hp-hrs. are required to roll one ton of steel. Assuming 70 percent load factor on the generating station, 13.8 pounds of steam are required to generate one horse-power-hour. It will therefore require 290 pounds of steam to roll one ton of steel when using the electric drive. Referring to Fig. 12, it will be seen that the reversing engine will require 570 pounds of steam per ton of metal rolled to ten elongations. This curve was plotted from the results of tests on a large modern reversing engine and may be taken as representative of the best American practice.

The first cost of the electrical equipment is from 10 to 15 percent higher than that of the steam engine, provided the steel mill generates its own power. Should central station power be purchased, which is frequently the case, the cost of electrical equipment will be between 30 and 40 percent less than that of the corresponding steam engine equipment.

When steam engines are used it is often necessary, in laying out the mill, to modify the design to bring the engines within reasonable distance of the boiler plant and condensing water. As the location of these auxiliaries is usually fixed by considerations other than the mill, it is easily seen that the best layout as far as rolling steel is concerned must give way to a modified design to satisfy these other conditions. With the electrically-driven mill no such modifications are necessary. The mill can be laid out to handle the steel in the fastest and most economical way without regard to the location of the power station. The power station may in turn be located close to the fuel and water supply and the power transmitted to the mill with merely a nominal loss. In this way an economical design may be reached both in the power plant and in the mill.

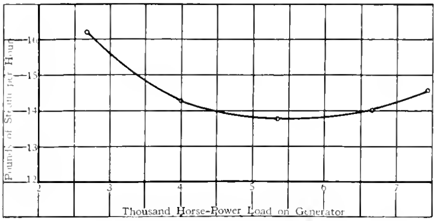

FIG. 11—ECONOMY CURVE OF 5000 KW STEAM TURBINE
Having 150 pounds steam pressure and 28 inches vacuum.

From the foregoing it will be seen that no effort has been spared to make the electric drive for reversing mills a more economical and a more convenient drive than the reversing steam engine, and this without sacrificing reliability. That this end has been attained is shown by the fact that the electric drive has been chosen in practically all of the new mills, both proposed and under construction.

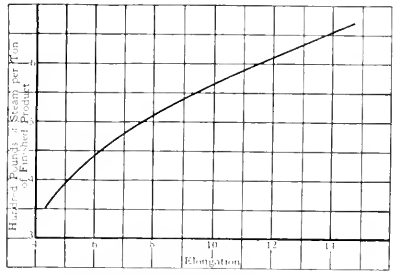

FIG. 12—STEAM CONSUMPTION PER TON OF STEEL
Using a modern reversing engine.

Commutating-Pole Machines With the Brushes Off Neutral

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Industrial Engineering Dept.,
Westinghouse Electric & Mfg. Company

ONE of the prime features of commutating-pole machines is that good commutation with a change in load may be obtained without shifting the brushes. The proper position for the brushes, or the neutral position, is determined for each machine by test before it leaves the factory, and the brushes are set in this position and so secured as to maintain the proper brush setting permanently. If for any reason this setting should be disturbed, there are three important effects which would result from such a shifting of the brushes. These are:—

1—A change in voltage in the case of a generator and a change in speed in the case of a motor.
2—Poor commutation.
3—Increased heating.

The extent to which these effects become evident depends upon the amount of brush shift and the design characteristics of the machine.

EFFECT ON VOLTAGE OF GENERATOR

A two-pole generator having also two commutating poles is represented in Fig. 1. Assume the direction of rotation to be clockwise and the brushes to be in the neutral position. The direction of the e.m.f.'s and currents in field and armature windings will be as shown, using the conventional form of representation. The inner circle of dots and crosses represents the direction of currents actually flowing in the armature coils, while the outer circle represents the direction of the e.m.f.'s induced in those same coils by the magnetic field set up by both the main and the commutating poles.

Noting the direction of the e.m.f.'s induced in the armature conductors on the right side of Fig. 1, it is seen that, although the e.m.f. induced in the conductors B_1 to e is in the same direction as that in the conductors e to f, the e.m.f. induced in the conductors f to B_2 is in the opposite direction. Similarly on the other half of the armature the e.m.f. induced in the conductors from B_2 to c aids that induced in the conductors c to d to the same degree that the e.m.f. induced in the conductors from d to B_1 opposes it. It follows then that with the brushes set in the neutral position the e.m.f. of the generator is neither increased nor decreased by the cutting of the commutating-pole flux.

Assume that the brushes are shifted in the direction of rotation to a position as represented by B_1 B_2 in

Fig. 2. The e.m.f. induced in the armature conductors from f to B_2 is in opposition to that induced in the conductors from B_1 to f, while on the other side of the armature a similar condition obtains for the conductors from d to B_1 in relation to those from B_2 to d. The effect of the commutating-pole flux then is in opposition to that of the main-pole flux, making the net flux cut per revolution less than with the brushes at neutral. Hence, with the brushes advanced in the direction of rotation the e.m.f. of the generator is reduced to a value less than that given with the brushes in the neutral position.

Assume next that the brushes are shifted against the direction of rotation to the position B_1 B_2 shown in Fig. 3. In this case the e.m.f. induced in the conductors from B_1 to c aids that induced in the conductors from c to B_2, and on the other side of the armature the e.m.f. induced in the conductors from B_2 to c aids that induced in the conductors from c to B_1, making the net flux cut per revolution equal to the sum of the main-pole and the commutating-pole fluxes, and therefore a maximum. It follows then that moving the brushes of a commutating-pole generator backward increases the generated e.m.f. In all of the above cases the speed is assumed to be constant.

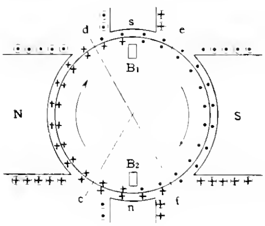


Fig. 1

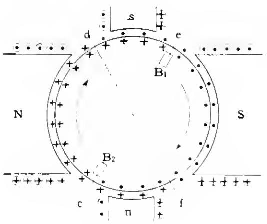


Fig 2

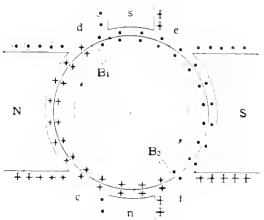


Fig 3

COMMUTATING-POLE GENERATOR
Fig. 1—Brushes at neutral.
Fig. 2—Brushes shifted forward.
Fig. 3—Brushes shifted backward.

EFFECT ON THE SPEED OF A MOTOR

Consider in a similar manner the effect on the speed of a commutating-pole motor when its brushes are shifted from the neutral position. Assuming that the impressed e.m.f. is constant, at any given load the counter e.m.f. will also be constant, since the counter e.m.f. equals the impressed e.m.f. minus the internal voltage drop of the machine. The speed will then vary inversely as the flux cut by the armature conductors, and the effect of brush position on the net flux cut per revolution can be considered in a manner exactly similar to that just employed in the case of the generator.

The conditions existing in the case of a motor with brushes in the neutral position are shown in Fig. 4. As in the case of the generator, the outer circle of dots and crosses represents the direction of the induced e.m.f.'s, and the inner circle the direction of currents actually flowing in the armature winding. Reference to the right half of Fig. 4 shows that the e.m.f. induced in the conductors from c to f is aided by that induced in the conductors from B_1 to c and opposed, to an equal extent, by the e.m.f. induced in the conductors from f to B_2. Similarly the e.m.f. induced in the conductors from B_2 to c offsets that induced in the conductors from d to B_1. Therefore the effect of the commutating-pole flux is neither to increase nor decrease the net flux cut per revolution, and hence the speed is not affected. In other words, the speed is the same in either direction of rotation. Because of this fact the neutral is commonly located, on test, by setting the brushes in such a position that the speed is the same in both directions of rotation.

If the brushes are advanced in the direction of rotation to the position shown in Fig. 5, the e.m.f.'s induced in the conductors B_1 c B_2 are all in the same direction, and the same thing is true in regard to the e.m.f's induced in the conductors B_2 c B_1. It is therefore evident that, with this position of the brushes, the net flux cut per revolution is a maximum, and hence the speed, which varies inversely as the flux, is a minimum, i. e., the speed decreases as the brushes are moved from neutral in the direction of armature rotation.

Where the brushes are shifted against the direction of rotation to the position B_1 B_2, as shown in Fig. 6, it is seen that the e.m.f. induced in the conductors from f to B_2 opposes that induced in the conductors from B_1 to f, and similarly the e.m.f. induced in the conductors from d to B_1 opposes that induced in the conductors from B_2 to d. The action of the commutating-pole flux in this case is therefore in opposition to that of the main-pole flux, reducing the net flux cut per revolution to a minimum and making the speed a maximum. In other words, the effect of shifting the brushes backward in a commutating-pole motor is to increase its speed.

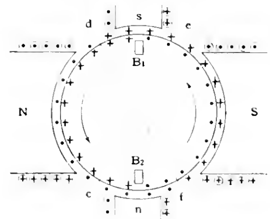


Fig 4

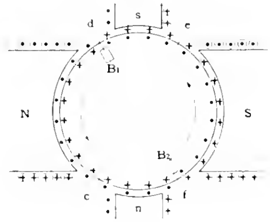


Fig. 5

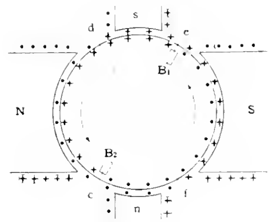


Fig 6

COMMUTATING-POLE MOTOR
Fig. 4—Brushes at neutral.
Fig. 5—Brushes shifted forward.
Fig. 6—Brushes shifted backward.

These effects are clearly shown by the curves in Fig. 7. The brushes were shifted as far as possible in each direction, their range of motion being limited by the size of the slot in the bracket which supports the bearing and brushholder. In the extreme positions the brushes were distant from the neutral about five percent of the pole pitch. This position of the brushes gave a full-load speed approximately nine percent higher or lower (according to whether the brushes were shifted backward or forward) than the full-load speed with the brushes at neutral. As the curves in Fig. 7 indicate, the greater the load, the greater the change in speed, since the commutating-field strength increases with an increase of load.

EFFECT ON COMMUTATION

In a commutating-pole machine, the commutating-pole winding is designed to produce as nearly as possible just the proper amount of magnetic flux to overcome the reactance voltage and thus reverse the current in those armature coils which are, at any moment, short-circuited by the brushes, during the time that they are short-circuited, the brushes being at neutral. If too much or too little flux is provided the e.m.f. induced thereby will not be of the proper value and sparking will result. Since there is a great variation in flux density in different parts of the neutral zone (the space between two consecutive main poles), it is evident that even a small shifting of the brushes means that commutation takes place in a field of quite different strength than with the brushes at neutral, and hence commutation is likely to be impaired.

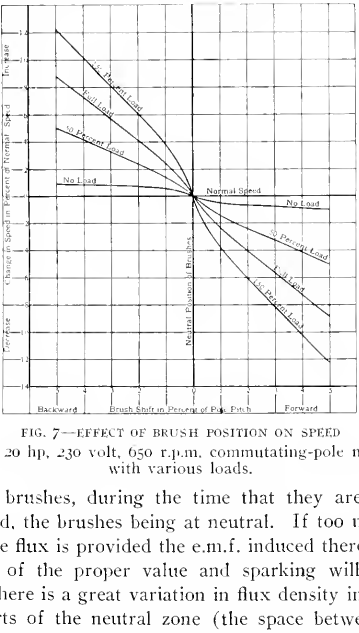


FIG. 7—EFFECT OF BRUSH POSITION ON SPEED
Of a 20 hp, 230 volt, 650 r.p.m. commutating-pole motor, with various loads.

In the motor referred to in Fig. 7, the commutation was very good throughout the entire range of brush positions, but this was unusual. The low speed of operation, the few turns per commutator segment and the narrow commutating zone (due to the fact that all of the coils undergoing commutation in any one neutral zone occupied the same slot) all contributed to this condition. Had the speed and number of turns per commutator bar been greater, the reactance voltage would have been increased, reducing the probability of good commutation; and if, in addition, the commutating zone had been very wide it would have been thrust into the fringing field of the adjacent main pole with even a slight shifting of brushes, and this would have produced a still greater tendency toward poor commutation.

EFFECT ON HEATING

It is practically impossible to predetermine from the design data of a machine what heat effects will result from a shifting of the brushes, but it is nevertheless a fact that if the short-circuited armature coils are moved into an abnormally strong field-flux, the e.m.f.'s induced in them may be the cause of abnormally high currents, perhaps five to ten times full-load current, and this may result in injurious overheating of the commutator. These currents cannot easily be measured, but their effect may become quite evident.

CONCLUSION

From the above discussion it follows that there are certain undesirable conditions which may result from the brushes of a commutating-pole machine being off neutral. It is possible to obtain a small change in the operating speed of a motor by shifting the brushes from the neutral position, provided that the commutation characteristics of the machine permit and rotation in only one direction is required. If, however, reversibility of operation is desired, it is obvious that the speed of a machine will be as much above neutral speed in one direction as it is below it in the other direction. Due to the fact that, when the brushes are shifted, the change in speed increases with an increase of load, a motor with a rising speed characteristic, when its brushes are at neutral, may be given a flat or drooping characteristic, and hence greater stability, by advancing its brushes from the neutral position, provided that bad commutation or excessive short-circuit currents do not result therefrom. Shifting of brushes for the sole purpose of obtaining a certain speed cannot in general be recommended as an advisable procedure.

In no part of the above discussion has the effect of field distortion produced by the armature cross-magnetizing ampere-turns been considered. Since none of the conclusions reached, except in the case of the curves in Fig. 7, are in any sense quantitative, a consideration of this effect would in no way alter the results.

Modern Types of Direct-Current Machines*

David Hall

THE modern type of direct-current machine with commutating poles and compensating windings presents a certain complication as compared with the plain non-commutating-pole machine. The user of such a machine naturally asks:—"Why the additional complication?" He may even think that his old machine is as good as can be desired, and for its particular application this may be true; yet the modern machine is cheaper. The materials—copper and the steel—are more expensive, yet the design of the modern machine is such that more output and better performance can be obtained from the same amount of material. The user is primarily interested in cost and performance. In other words, he wants a machine to perform a given duty satisfactorily. Simplification is, of course, desirable. To obtain certain characteristics may require additional parts, and one of the functions of design is to decide whether the additional parts and complications are justified by the improved operation. Before endeavoring to set forth the advantages or disadvantages of any particular construction or type of machine, it is advisable to consider the electrical machine in its most elementary form. A simple view of an electrical machine makes any of its functions and possibilities very evident. Hence it is justifiable to spend some time in forming fundamental conceptions and fixing these conceptions clearly in the mind.

A DIRECT-CURRENT motor or generator may be considered as a certain mass of steel to provide a path for magnetic flux, and a mass of copper to provide a path for electric currents. In this conception, there are the two main elements,—*flux* capacity and *current* capacity. These two elements constitute the backbone of the machine. Further deductions as to what can be obtained from a given machine will all revert to these two factors.

FLUX CAPACITY

In rotating electrical machines, the primary interest centers in the total flux which passes through the air-gap between the stator and the rotor, and which is cut during rotation by the belt of copper conductors, distributed on the armature. The *gap area*, that is, the circumference of the armature multiplied by the length of the armature core, provides a measure of this flux capacity. If D = diameter of armature, and L = length of armature, the flux is proportional to DL.

While the flux capacity for a unit area of gap is not the same for all machines, yet for a given class of machine the air-gap area can be considered a fairly accurate measure of the flux capacity, and it is therefore evident that the flux capacity of any machine increases directly as the diameter of the rotor increases, and directly as the length of the rotor increases. Thus, flux capacity may be looked upon as air-gap area, and any changes which increase or decrease the air-gap area would cause a corresponding increase or decrease in flux capacity. The steel above and below the air-gap may be looked upon as a necessary evil—simply a carrier to make possible the air-gap flux, as also may the field copper be looked upon as a necessary evil—simply a means of producing the air-gap flux.

*Revised from a paper read before the Association of Iron and Steel Electrical Engineers, Sept. 20, 1916.

CURRENT CAPACITY

The conductors adjacent to the air gap may be considered as a belt, having a definite area of cross-section; that is, the total copper section is equal to the cross-section of the copper in one slot, multiplied by the number of slots. If we look upon this total cross-section as the area of one wire, we have a measure of the ampere-wire capacity, that is, the current which all these conductors would be capable of carrying when connected in parallel. If this cylindrical belt of conductors be considered as one large wire, then the total current which is carried represents the ampere-wire capacity of the winding. The ampere-wire capacity is entirely dependent on this section of the copper, hence, other things being equal, the section will increase directly as the diameter of the armature increases, and it is independent of the length of the armature; that is, armature-wire capacity is proportional to D. While the ampere capacity for a unit area of copper is not the same for all machines, yet for a given class of machines the copper section may be considered a fairly accurate measure of the ampere-wire capacity.

With flux capacity proportional to gap area, and ampere-wire capacity proportional to copper section, a measure of a given machine is available, whether it be a motor or a generator, alternating or direct current, and whether it stands still or rotates. The windings may be considered as a cylindrical copper cage; the total cross-section of all of the bars of this cage is a measure of the ampere-wire capacity, and increasing the length of the cage does not change the ampere-wire capacity. It is evident that the ampere capacity of these wires will depend on how well they are ventilated; consequently for the same temperature rise, the better the ventilation, the more current can be carried by a given section of copper. Hence the necessity of well-ventilated armatures. With a given ventilation, a given diameter of armature and a given section of armature winding, the ampere-wire capacity is fixed. That is, if all the conductors surround-

ing the armature are considered as a single wire, there is sufficient copper section for a definite current. However, if these armature conductors are so connected as to use one-half of them to carry current from the front of the armature to the back, and the other half to carry the current from the back of the armature to the front, the number of conductors will be doubled and the number of amperes halved, but the product of the amperes and the conductors, that is, the ampere-wire capacity, will remain constant. The same armature may have 1000 amperes and one wire, or one ampere and 1000 wires.

So far output or speed have not been mentioned. It is evident that at zero speed the output is zero. If the armature is rotated, the voltage generated will be dependent on the flux, the speed, and the number of wires in series, and as the output is dependent on the product of voltage and amperes, it must be proportional to flux, speed, amperes and wires. It is the variation of these four factors which constitutes the many ratings which are obtainable from a given mass of steel and copper.

Output = Flux × Speed × Amperes × Wires × Constant— From this simple formula a number of facts are easily observed. If a maximum output is to be obtained from an armature of given dimensions, the flux must be made maximum, and the ampere wires must be made maximum. On a given armature there is only a certain space available for flux and wires. It is not essential that an armature of given dimensions and for a given rating be worked always at the same flux, but when the flux is fixed, the wires will also become fixed; either of these may be changed, but they must change together. If the flux is increased, the wires will be decreased, and vice versa. Hence it is that from the same diameter and length of armature a machine of a given rating may be designed with a relatively large amount of flux and a small number of ampere wires or, on the other hand, the machine may be made with relatively small amount of flux and a large number of ampere wires. The former machine will require a large amount of steel and a small amount of copper; the latter machine the reverse. As the weight of the machine is determined principally by the amount of steel, the former machine will be heavy as compared with the latter. Thus it is that two different designs for a given rating may be made; one might be called a steel machine, that is, a heavy machine; the other might be called a copper machine, that is, a light machine. These different relative proportions of steel and copper constitute different performances and cost, and it is around these factors that designs may be said to revolve.

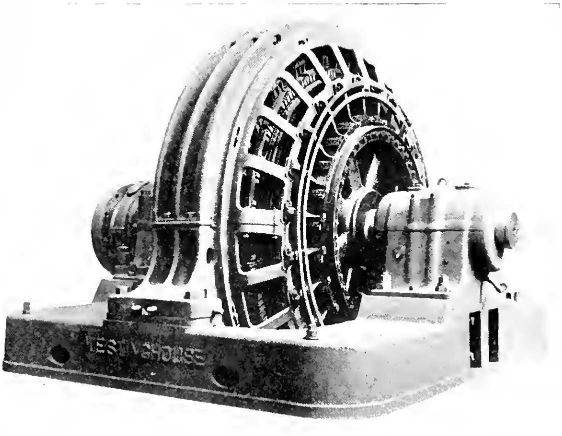


FIG. 1—8000 HP COMPENSATED MOTOR FOR REVERSING SERVICE
For another view of this motor, see Fig. 7, p. 529.

In observing the above formula and considering that the flux, as it enters the air gap, is perpendicular to the wires on the armature, one might suggest that the output could easily be increased by making the armature slots narrow and deep instead of wide and shallow. This is true, and the slots are made as deep as can be permitted, taking all other factors into consideration. As deep slots increase the self-induction due to current reversal and as deep conductors may introduce other losses at high speeds, slow-speed machines contain deep slots while high-speed machines contain relatively shallow slots. The high-speed machine ventilates better than the low-speed machine, and consequently the copper can be worked at a higher density. As a rule, the high-speed machine will have a higher self-induction, and in order to obtain good inherent commutation it generally becomes advisable to use relatively shallow slots. From the standpoint of efficiency, these relative proportions are also desirable; that is, slow-speed machines require a large amount of copper, and high-speed machines can be made with relatively less copper.

From the same frame of a machine there may be obtained many outputs, depending on the speed. For example, from the same frame there can be obtained 100 kw at 100 r.p.m., 200 kw at 200 r.p.m., and 1000 kw at 1000 r.p.m., speaking generally, as regards the flux and ampere wires. For changes in voltage, changes in the number of poles will become necessary. If a machine is properly constructed to give 100 kw at 100 volts, when running at 100 r.p.m., this same machine will give 200 kw at 200 volts when running at 200 r.p.m., and 1000 kw at 1000 volts when running at 1000 r.p.m., if there were not other limitations, both mechanical and electrical, which prevent this simple procedure being applied over a very wide range of ratings and speeds. As the voltage obtained from a given frame is dependent on the flux, speed and wires, if the speed is set, the wires will have to be increased in order to increase the voltage; and as the product of amperes and wires is a constant, the wires can only be increased by reducing the

ampere capacity; hence it is that the same frame of a machine may be used to give 100 kw, 100 volts, 1000 amperes at 100 r.p.m., and also 100 kw, 200 volts, 500 amperes at 100 r.p.m. The latter machine has twice the number of wires and twice the voltage, but one-half the ampere capacity. In other words, the capacity of a given frame is proportional to its speed, and the voltage at a given speed is proportional to the wires connected in series on the armature.

If the total current is large, it is, in general, desirable to have a relatively large number of paths in the armature. Hence, on large current machines, a large number of poles are used, and on small current, high-voltage machines, a small number of poles constitute the best design. Increasing the length of a given armature increases the flux capacity, but it does not increase the ampere-wire capacity; hence the output of the armature will increase directly with its length. Increasing the diameter of an armature increases both the flux capacity and the ampere-wire capacity; hence the output of an armature increases directly with the square of the diameter. Thus output is proportional to D^2L, and $kw = D^2 \times L \times r.p.m. \times output\ factor$.

The aim of the designer is to obtain a high output factor, that is, to obtain a large output for a given armature diameter and given length of armature; in other words, he endeavors to proportion the machine so as to get maximum output at minimum cost. One way of accomplishing this is to ventilate the various parts so as to enable the maximum watts to be dissipated with least amount of heating. For example, the armature core may have a liberal number of air ducts, and the armature spider may be designed to easily admit the air into the core. This output factor represents what may be called the loading factor of the armature, or, in other words, the magnetic flux per inch of length, and the armature ampere wires per inch of armature diameter.

Let F = Number of lines of flux per inch of diameter per inch of length of armature.

A = Armature ampere wires per inch of armature diameter.

Then total flux $= F \times D \times L$.

As the cutting of 10^8 magnetic lines per second by one conductor generates one volt, and as each conductor or wire on the armature cuts the total air-gap flux once in one revolution, the expression for the voltage generated is,—

$$Volts = \frac{F \times D \times L}{10^8} \times \frac{R.p.m.}{60} \times \frac{Wires}{Circuits}$$

In this formulae, $\frac{wires}{circuits}$ represents the number of wires in series on the armature. For example, a six-pole machine may have the winding so connected to the commutator bars as to give six paths in the armature. That forms what is generally called a multiple armature winding, and the ends of an armature coil connect to adjacent commutator bars. This type of winding is used in practically all large machines, that is, the number of circuits in the armature is the same as the number of poles. The armature winding may be so connected to the commutator as to give only two paths in the armature. The latter winding would be called a two-circuit winding. With the same number of commutator bars and the same number of turns per coil, the six-circuit winding will give one-third as many volts as the two-circuit winding, but it would have three times the current capacity. It will be observed that the ampere-wire capacity is the same in both windings. If the six-circuit winding gives 100 volts and 3000 amperes, the two-circuit winding would give 300 volts and 1000 amperes.

Multiplying both sides of the above equation by amperes, we obtain:—

$$Volts \times Amps. = \frac{FDL}{10^8} \times \frac{R.p.m.}{60} \times \frac{Wires}{Circuits} \times Amps.\ per\ wire \times Circuits$$

$$= \frac{FDL}{10^8} \times \frac{R.p.m.}{60} \times Ampere\text{-}wires.$$

$$= \frac{FDL}{10^8} \times \frac{R.p.m.}{60} \times A \times D$$

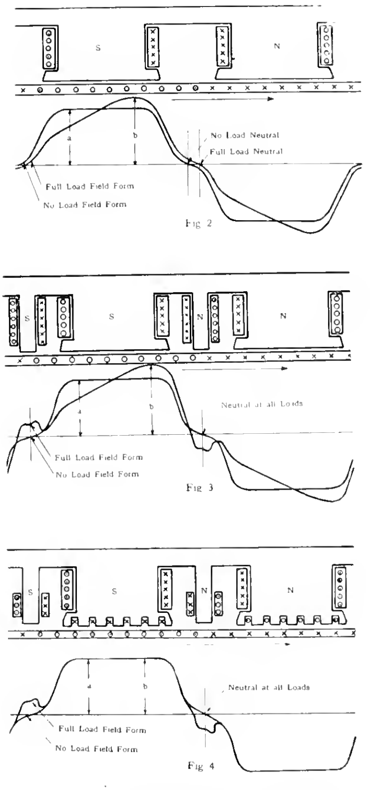
$$= D^2 \times L \times R.p.m. \times \frac{(F \times A)}{60 \times 10^8}$$

This equation provides an expression for the total watts of the machine. The term in the parenthesis is the output factor. The output which is obtainable from a given size armature at a given speed depends upon the flux per inch and the ampere wires per inch. The higher these two factors are worked, the more will be the output from a given armature. These two factors have their limits. If the flux is too high a large amount of field copper is required, at a consequent increase in cost. Also, if the flux density in the armature teeth and core is made high, the iron loss will be high. The actual loss in the iron will increase much faster than the density increases. In slow-speed machines, the iron loss is usually very small because of the low frequency; consequently, this does not become the limiting factor, but in high-speed machines, that is, machines of 30 cycles or more, the iron loss begins to be a considerable factor in the total losses, and must be kept down in order to make high efficiencies possible.

The ampere-wire loading of the machine, as has been observed, is a direct factor in the output; hence the desirability of making this high. The current density which can be used in the armature conductor will depend on the ventilation, the permissible heating and the efficiency which must be obtained. The section of copper which can be put on a given armature will depend on the size and shape of the slots. As flux capacity and ampere-wire capacity are equally important in obtaining output, and as the increase of one means the decrease of the other, the design becomes a compromise. If the armature slots are made narrow and deep, they interfere the least with the available section of iron for the flux. As has long been known, armatures with narrow deep slots have more self-induction due to current reversal than armatures with wide shallow slots, and while the capacity of such armatures from the heating standpoint, as shown by our formulae, may be very large, the commutation limit might be much lower. The above for-

mulae have in no way taken commutation into consideration, and if there is any one element in a direct-current machine which is more important than all other elements it is commutation.

For many years, previous to their general use, commutating poles were well known, but the requirements imposed by the users of electrical machines were being met in a reasonably satisfactory manner with the old non-commutating-pole designs. Necessity for machines with greater overload capacity, for machines of high speed, for wide range variable speed motors, for generators capable of operating over a wide range of voltage, for machines which would stand reversal either mechanically, electrically or both, has led to the general introduction of special means for insuring good commutation. This has not come without the addition of some new parts, and without a certain relative degree of complication, but the general improvement in operation since the introduction of commutating-pole and compensated machines has been so marked as to render the old type of machines non-competitive for most purposes.



FIGS. 2, 3 and 4—FIELD FORM CURVES
Of a non-commutating-pole generator (Fig. 2); of a commutating-pole generator (Fig. 3), and of a compensated generator (Fig. 4).

The old non-commutating-pole machine had no fixed neutral position for the brushes. The generator required that the brushes be moved forward; the motor required that the brushes be moved backward. The amount of brush shift was dependent on the load; consequently, many non-commutating-pole machines cannot be satisfactorily operated through a wide range of load without changing the brush position. The commutating conditions often depend on the field strength, and many pole-tip constructions were devised to assist in producing a suitable magnetic field for commutation. Armatures were designed with wide shallow slots, thus reducing the output in other directions, all for the sake of improving the commutation. That is not all, for, with special pole-tip construction, the relative strength of armature flux in the main field was of great importance if good commutating conditions were to be maintained. This restriction prevented good commutation over either a wide range of load or over a wide range of voltage, and motors could not be made to operate well over a wide range of speed.

In order to meet these inherent characteristics of non-commutating-pole motors and generators, there appeared on the market various well-meaning designs, whereby the neutral zone of commutation was supposed to be more or less fixed. All of this goes to show to what a great extent the designer of direct-current machines has been concerned with commutation, and even with the best type of construction it was impossible to make machines of such ratings as are commonplace today. This is the fact which is of interest to the consumer, for, as has been previously pointed out, the output from a given size armature is proportional to the speed and, with the commutation provided for, the speed has been increased, and the cost and the weight per kilowatt has been correspondingly reduced.

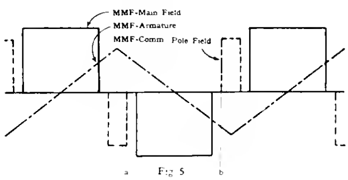
Reversing motors for large blooming mills, some of which today carry swings of more than 10 000 amperes at 1200 volts, would be impossible without special provisions for commutation. High-speed generators supplying energy to such reversing motors would not have been considered under the old type of design. The motors for speed variations of 4 to 1 and generators which will commutate throughout the entire range of voltage have widened the field of application of electrical machinery. These are not all the advantages, for, with good inherent commutation, graphite brushes can be used, as a high brush contact resistance is not necessary. Such brushes have a low coefficient of friction, and they do not wear the commutators as the old carbon brushes did. Both the life of the commutator and the life of the brushes are greatly lengthened. Hence it is that operating troubles and maintenance expense have been greatly reduced by improved commutation.

TYPES OF CONSTRUCTION

There are two general types of field construction,—one type using commutating poles only, and the other type, which is a variation of the commutating-pole type, being called a "compensated machine." The commutating-pole machine is made by introducing additional

small poles between the main poles. The small poles are magnetized by a winding in series with the armature, and the brushes are so placed that the coil during commutation comes under the influence of the flux from the commutating poles, which flux is of such value and direction that cutting it produces in the coil undergoing commutation a voltage which neutralizes the voltage of self-induction. In a generator the flux from the commutating pole must be in the same direction as the flux from the main pole immediately ahead, and in a motor the flux from the commutating pole must be in the same direction as the flux from the main pole immediately behind. An easy way of remembering this relation is to consider that in a generator a piece of the main pole is moved *backward,* instead of the brushes being shifted *forward,* and in a motor a piece of the main pole is moved *forward,* instead of shifting the brushes *backward.*

This brings the neutral position midway between the main pole pieces for either a motor or a generator, and by connecting the commutating-pole winding in series



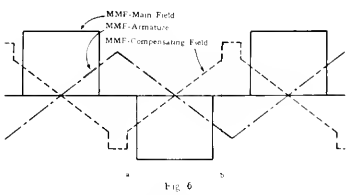


FIG. 5—MAGNETOMOTIVE FORCE IN A COMMUTATING-POLE GENERATOR

FIG. 6—MAGNETOMOTIVE FORCE IN A COMPENSATED GENERATOR

with the armature a change from generating load to motor load automatically changes the polarity of the commutating poles. Thus, such a machine is suitable for either motor or generator operation without any movement of the brushes. This characteristic is very important, and it has opened a wide field of application which could not be covered by the older type of machines.

The next principal variation from the commutating-pole machine is the compensated machine; in fact, a compensated machine may be looked upon as a modified commutating-pole machine. The commutating-pole machine has the exciting winding concentrated about the commutating pole, while the compensated machine has a part of the exciting winding distributed in the main pole face. The total excitation is the same in both cases.

As the commutating-pole machine is simpler in mechanical construction than the compensated machine, the question naturally arises as to why the latter construction is used. In order to explain this it is necessary to consider the function of the commutating-pole winding. Figs. 5 and 6 show the magneto-motive forces which are present in both type of machines. The essential difference, as will be noticed from an inspection of the diagram, is that in the commutating-pole machine the armature reaction is not neutralized in the zone *a-b,* while on the compensated-pole machine the armature reaction is completely neutralized under the main pole. In order to maintain the best commutating condition, the flux from the commutating pole must change in exact proportion to the change of load. As soon as there is any saturation in the commutating pole this exact relation is destroyed and the commutation limit is soon reached. It is therefore undesirable to use shunts around either the commutating-pole winding or the compensating winding, as the presence of shunts may destroy the straight line relations between the armature current and the exciting current which produces the commutating flux.

As the commutating pole must carry both the useful flux for commutation and also any leakage flux which may be produced by its winding, it is evident that reducing the leakage flux will increase the commutation limit of the machine. The most effective way of reducing this leakage flux is to distribute the commutating-pole exciting field winding in the main pole faces and thereby increase the length of the path of leakage flux. This construction produces what is called a compensated machine, and it possesses two distinct advantages over the plain commutating-pole machine. It has a greater maximum commutating capacity and, as the armature cross-magnetization is neutralized under the main poles, the maximum voltage between adjacent commutator bars is correspondingly less. By taking advantage of these points it becomes possible, by the aid of compensation, to increase the speed of generators and to make motors which will meet more difficult cycles of operation. Within the commutating limits the commutating-pole machine commutates just as well as the compensated machine, but the limiting factor in commutation is the saturation of the commutating-pole magnetic circuit. The main factor in saturating this circuit is the leakage flux and, as there is less leakage in this part of the compensated machine, the overload limit is correspondingly increased.

As the number of commutator bars per pole decreases with an increase of speed, a high average voltage between adjacent commutator bars is the result, and if the number of commutator bars is arbitrarily increased in order to obtain low average voltage between bars the armature reaction is correspondingly increased, and the distortion of the main flux becomes greater, resulting in a high peak voltage between adjacent commutator bars. As has been shown in the compensated machine, there is no distortion of the main pole flux; consequently, with the same degree of safety, a higher average voltage between commutator bars is permissible; that is, with the same peak voltage between commutator bars, the com-

pensated machine can have a higher average voltage between bars than the commutating-pole machine. Hence, for very high speeds, the compensated machine makes higher ratings possible. For the same reason, the compensated machines makes possible higher voltage machines for a given speed.

The pole face windings and their necesary connections introduce a certain amount of complication which is inherent to the compensating windings. It is a fact that the compensated machine is not as easily dismantled and not as easily repaired as the commutating-pole machine and, for pure simplicity of construction and minimum number of parts, we must admit that the old non-commutating-pole machine is superior to either of the later types. Hence the better performance is obtained at a sacrifice of simplicity, and a universal application of compensated machines would be as much of an error as would be an attempt to apply non-commutating-pole machines to all classes of service.

VOLTAGE REGULATION OF GENERATORS

It is generally known that the voltage points on the regulation curve of a compound generator at different loads do not lie in a straight line, but they lie on a curve, the half-load voltage being higher than either the no-load or the full-load voltage when the compounding is adjusted for the same voltage at both no-load and full load. This characteristic is due to the cross-magnetizing effect of the armature winding, and it is present in both non-commutating-pole and commutating-pole machines. The magnitude of this effect depends upon the relative strength of armature to main field flux and to the degree of saturation in certain parts of the magnetic circuit. The chief difference between the compounding of non-commutating-pole machines and commutating-pole machines is that in the latter type less series turns are required to give a certain compounding, because in a commutating-pole machine the brushes are placed in the neutral position and there is no *demagnetizing* effect from the armature. In practice the series coils of a commutating-pole machine will have less resistance than the series coils of a corresponding non-commutating-pole machine and, to parallel two such machines, it is often necessary to connect a resistance in series with the series winding of the commutating-pole machine. The compensated generator has a straight-line voltage regulation. This is because the cross-magnetizing effect of the armature is neutralized by the pole face winding. No trouble, however, is experienced in operating all three types in parallel. For parallel connections of commutating-pole or compensated machines, the commutating-pole winding and the compensating winding are treated as a part of the armature circuit; that is, the equalizer is brought out where the inside end of the series winding connects to the outside end of the commutating-pole or compensating winding.

The question of generator voltage regulation is often confused with the change in voltage, which occurs with a sudden change of load. The two characteristics are entirely different and no attempt should ever be made to apply the same limitations to them. Voltage regulation, as generally referred to, applies to a change in voltage due to a gradual change of load, the voltage being read by an ordinary voltmeter, as distinguished from an instantaneous change of load. Such change of load extends over a period of at least a few seconds and is of sufficient time to permit of a settling of the voltage to the usual condition of operation. In certain classes of service the load changes very suddenly over a very wide range. These changes, if momentary, produce variations in voltage which are of very short duration, but of large magnitude. For example, suddenly throwing full load on a generator may reduce its voltage to almost zero and suddenly throwing off full load may increase the voltage 25 percent. These changes, which are of very short duration, can only be measured by an oscillograph and, except for circuits used for lighting, they

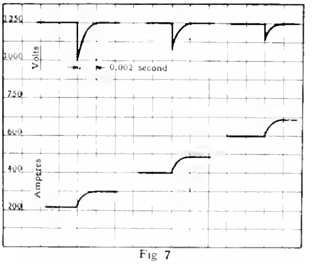


Fig 7

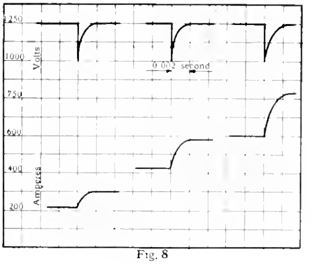


Fig. 8

FIGS. 7 and 8—VARIATIONS IN VOLTAGE
Due to a sudden increase of 80 amperes (Fig. 7) and 38 percent of load (Fig. 8) on a 500 kw. 1200 volt, 600 r.p.m. direct-current generator.

are of no consequence. All types of direct-current generators show momentary changes of voltages with instantaneous changes of load, as illustrated in Figs. 7 and 8.

EFFICIENCY

In efficiency there has been no particular gain made in changing from the non-commutating-pole construction; in fact, it is evident that the introduction of additional windings has occasioned additional losses. To counteract this effect, which would in itself have meant a reduction in efficiency, it can be said that less total losses in the main field are necessary, and one very important fact in this connection is that, with a special means of taking care of commutation, deeper slots are

permissible and, consequently, a more liberal section of armature copper can be used, thus reducing the losses. As the maximum point on an efficiency curve is where the variable losses are equal to the constant losses, it

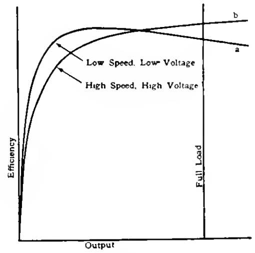


FIG. 9—TYPICAL DIRECT-CURRENT GENERATOR EFFICIENCY CURVES

might be noted that in either low-voltage or low-speed machines the constant losses are generally low as compared to the variable losses and the curve takes a shape like *a*, Fig. 9, in which the maximum point on the efficiency curve occurs at less than full load. In high-voltage or high-speed machines the constant losses are generally higher as compared to the variable losses, and the efficiency curve takes a shape similar to *b*, Fig. 9, in which the maximum point on the efficiency curve occurs beyond the full load.

Hand in hand with the improvement in commutation there have been many improvements along other lines, both electrical and mechanical. Armature coils, formerly made of wire, are made of strap wherever possible.

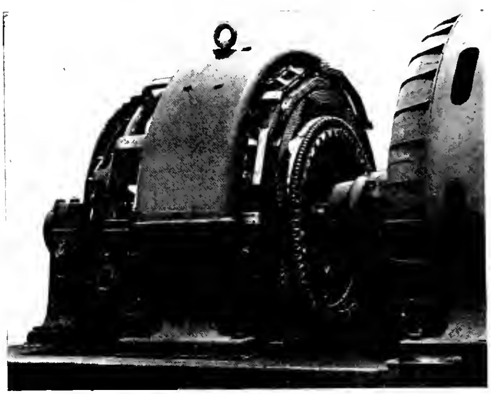


FIG. 10—TYPICAL HIGH-SPEED COMPENSATED GENERATOR

In many cases cotton insulation has been replaced by mica and asbestos. Cast steel and rolled steel have taken the place of cast iron, thus improving the magnetic quality, increasing the strength, reducing the weight and the size. Better brushes are contributing to long life of commutators, and better commutation has made possible the use of softer grades of brushes—brushes which contain graphite, and which have no abrasive quality, and which possess the desirable quality of a low friction coefficient.

Various lines of direct-current machines have been designed embodying special means such as described for insuring good commutation. Some of these lines have been made especially for steel mill application, such as the steel-mill motor. A typical compensated motor for a reversing blooming mill is shown in Fig. 1. Such motors have a special rotor construction, which is made to withstand the shocks which are characteristic of this application. The armature windings are braced at both ends outside of the armature core, and all parts are more rugged than is necessary for ordinary classes of service.

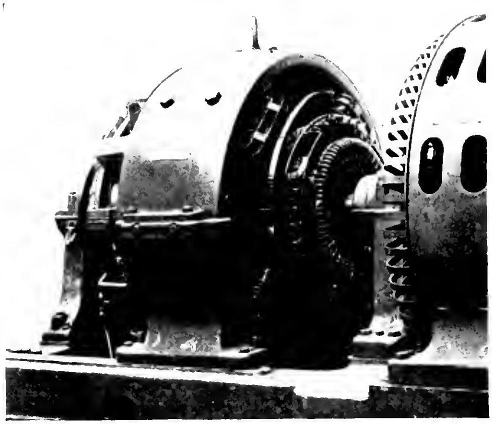


FIG. 11—A DIFFERENT ARRANGEMENT OF COMPENSATING WINDINGS
These generators will carry severe momentary overloads without flashing or undue sparking.

In Figs. 10 and 11 are shown typical motor-generator sets. The direct-current generators are compensated and are capable of supplying momentary loads of three times their normal heating load.

Altogether, the direct-current machine has been greatly improved by the introduction of special means of securing good commutation. Its field of application and its flexibility have been greatly widened, and at the same time the cost and the weight have been materially reduced. As an exceptional illustration of the satisfactory service of modern motors, the writer has in mind a particular rolling mill where some 175 motors, aggregating 5000 hp, are in use, and in the last two and a half years the only repairs necessary to these 175 motors have been the re-winding of two armatures.

Some Business Principles

V. Karapetoff
Consulting Engineer,
Springfield, Mass.

THE following thoughts were prepared, under the title of "Some M.C. Principles," for the young engineering apprentices of the New England Westinghouse Company. The abbreviation "M.C." stands for "Millennium Crowd," which I gave to these junior engineers, intimating by this name that they should consider the millennium as if it were present; in other words, they should work without considering their faults and limitations and do the way perfect men would act.

ACCURACY

WE BELIEVE in accuracy in all our acts, statements, reasoning, workmanship, appointments, promises, drawings; in fact, in everything that is associated with our name.

VERACITY

We believe in veracity towards our associates, superiors, subordinates, clients, competitors, beggars, benefactors, members of our family, and especially towards our own conscience when it is accusing us.

FULFILLING A PROMISE

We believe that fulfilling one's promises in spite of all obstacles and against one's own advantage is the greatest single asset and virtue in business.

INITIATIVE

We believe in initiative, which in the business world usually means helping everyone around you without being told to do so and without being obnoxious.

SYSTEM, ORDER AND SELF-DISCIPLINE

We believe in system, order and self-discipline for the sake of those with whom we are associated. This is but a specific case of the Golden Rule and it works fine. We do not tax our memory beyond reason, because an omission or a misstatement may hurt a friend of ours.

HARMONIZING VIEWS

We believe in harmonizing views whenever possible and in foregoing the mention of a distinct name for the sake of friendship with those to whom this name may be offensive.

BEING OPEN-MINDED

We believe in being open-minded, because we remember many a case when we were glad that things did not happen our way and sorry when they happened the way we wanted them to.

GIVING FULL CREDIT TO OTHERS

We believe in giving full credit to others, because real worth cannot be hidden long and a professional thief is not a very far-sighted individual.

CO-OPERATION

We believe that a lasting monument is usually a result of wise and unselfish co-operation wherein everyone works on the part he is best fitted for and is so busy and interested in the work that he forgets to hew his name on the stone.

KEEPING SUPERIORS POSTED

We believe in keeping our superiors posted on what we are doing, so as to simplify their supervision over us. Having finished a task we report at once, or if the job could not be done we notify the head man without delay. We train our boss so that when he does not hear from us he knows that everything is O.K.

SURPRISES SHOULD NOT BE SPRUNG

We believe that no surprises should be sprung on our business associates in the form of an unexpected official act or letter. It is both wise and honorable to discuss a matter with a person informally and to find his attitude towards it before taking a decisive step.

PERSUASION RATHER THAN COMMAND

We believe in persuasion rather than command for the same reason for which we prefer an electrically-started automobile. Incidentally, the most efficient organizations are those in which men understand what they are doing and believe in the method of procedure.

MOBILIZING RESOURCES

We believe in mobilizing the resources of our organization when an important problem arises. We see to it that those whose skill or knowledge exceeds ours are drawn into the discussion and not kept out for a selfish purpose.

Parallel Operation of Frequency-Changer Sets

F. D. Newbury

Frequency-changer sets, used to interchange power between two circuits or systems of different frequency, may be of several different types; in the type here considered a synchronous motor of one frequency drives a synchronous generator of another frequency. Parallel operation of such motor-generator sets requires that both the motors and the generators shall respectively be in synchronism.

SYNCHRONIZING TWO FREQUENCY CHANGER SETS

In order that this explanation may be simplified, it will be assumed that the armature windings of the various machines are identical in location and sequence of terminal coils. Then the position, at some chosen time, of a pole of the rotating field (with respect to a group of armature coils covering one pole pitch) represents the phase of the voltage generated in the motor or generator winding; accordingly, in the following explanation the "position of the rotor pole," or "polar position," will signify the voltage phase. Thus if two synchronous motors are operating from the same supply system without load the polar positions of the two motors will be the same. Likewise, before two generators can be synchronized, the polar positions of the two rotors must be made the same. A distinction will also be made between "polar position" and "rotor position;" the former will mean the phase of the generated voltage, while "rotor position" will mean the mechanical position of the rotor without reference to magnetic or electrical conditions. This distinction may be illustrated in the following way:—If a synchronous motor is in synchronism with a generator and is then caused to slip two poles, its polar position will not have been changed, while its rotor position will have been changed.

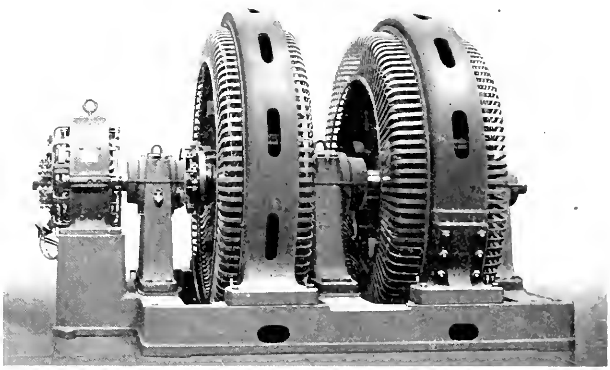


FIG. 1—FREQUENCY-CHANGER SET

Showing motor frame mounted in cradle for rotation. The usual commercial range of this frame-shifting device is about four mechanical degrees; on a ten-pole motor this corresponds to 20 electrical degrees.

In synchronizing two engine-driven generators, it is not difficult to bring the two rotors into the same polar position, since the two rotors may be independently controlled in speed and the relative polar positions are continuously changing. Moreover, the two generators will have the same polar positions (that is, will be in synchronism) when any pole of one generator has the same position as any pole of the same polarity of the other generator. There are as many rotor positions that are correct for synchronizing as there are poles of the same polarity on the incoming generator.

When a synchronous motor-driven frequency-changer set is to be synchronized with another similar set, the same general principles apply, but the rigid mechanical connection between the poles of the motor and the poles of the generator considerably reduces the number of correct rotor positions of the motor. In the case of two sets, the two motors must have the same polar positions and at the same time the two generators must have the same polar positions. In Fig. 2, which represents a 4 pole-6 pole set, if the two motors are connected to the supply circuit so that, in both sets, motor poles N_1 have the same position, then the generator poles N_1, in both sets, will have the same position and the sets will be in synchronism on both ends. If, however, the two motors are connected to the supply circuit so that pole N_1 in one motor has the same position as pole N_2 in the other motor (which is a possibility, considering the motors alone), then pole N_1 in one generator will have the same position as pole S_2 in the other generator, and the two generators will be 180 degrees out of phase at the same time that the two motors are in phase. If the two motors are considered alone, there are two correct rotor positions; if the two generators are considered alone, there are three correct rotor positions; but if the motor and generator are tied rigidly together, as in frequency-changer sets, there is only one correct rotor position for the incoming motor. For the sake of brevity, "synchronizing position" will be used to denote that rotor position of the incoming motor in which both motor polar positions will be the same and both generator polar positions will be the same. In general, the number of synchronizing positions in any pair of sets is equal to the greatest common divisor of the number of possible synchronizing positions of the motor and of the generator considered as separate machines. The synchronizing positions for the separate machines are equal in number to the number of pairs of poles. Thus

in the 4 pole-10 pole set shown in Fig. 3 there are two synchronizing positions for the motor, considered alone; there are five synchronizing positions for the generator, considered alone; and there is only one synchronizing position for the set. In the 4 pole-8 pole set, in Fig. 4, there are two synchronizing positions in the set; or as many as for the motor, considered alone; in the 10 pole-24 pole set, in Fig. 5, there is, again, only one synchronizing position for the second set.

If the number of correct synchronizing positions of the motors or generators, considered separately, is increased, the number of synchronizing positions for the second set will also be increased. Thus, if the polarity of the south poles of the incoming generator, considering the two generators as separate engine-driven units,

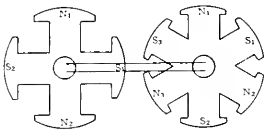


Fig. 2

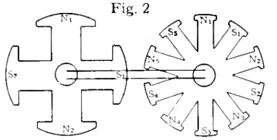


Fig 3

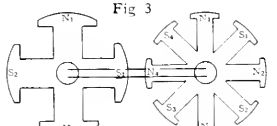


Fig 4

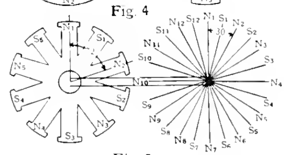


Fig. 5

FIGS. 2 TO 5—FREQUENCY-CHANGER ROTOR DIAGRAMS
Fig. 2—40 to 60 cycles; 4 and 6 poles.
Fig. 3—25 to 62.5 cycles; 4 and 10 poles.
Fig. 4—25 to 50 cycles; 4 and 8 poles.
Fig. 5—25 to 60 cycles; 10 and 24 poles.

be changed, each of the generator poles at one time or another will be a north pole, and there will be as many synchronizing positions as there are poles. Considering the motors alone, by reversing the motor excitation, the number of motor synchronizing positions may also be doubled. In the 4 pole-6 pole set, Fig. 2, it was shown that if pole N_1 of one motor had the same position as pole N_2 of the second motor, the pole N_1 of the first generator would have the same position as pole S_2 of the second generator, and that the two generators would be 180 degrees out of phase. Obviously, by reversing the excitation of the second generator, the south pole is changed to a north pole, thereby bringing two generator poles of the same polarity into the same position, and the two sets into synchronism.

In the 10 pole-24 pole combination, Fig. 5, the number of set synchronizing positions can be increased by reversing the motor excitation. Consider that the two motors are connected to the supply circuit so that the poles N_1 of both motors are in the same position. Generator poles of the same polarity will also be in the same position, but the generators are not connected in parallel.

Now assume that the excitation of one motor is reversed. The pole N_1 (which is now a south pole) will drop back and the pole S_1 will occupy the position that N_1 did occupy. The motor has dropped back one pole—or, as it is called, has "slipped a pole"—and its new position is 180 magnetic degrees, or 36 mechanical degrees, behind its original position. The generator of the second set has been pulled back 36 mechanical degrees, or 432 magnetic degrees. Pole N_2 of the second generator is now 6 mechanical degrees, or 72 magnetic degrees, back of pole N_1 of the first generator. If this process of slipping a pole is repeated until pole S_3 of the second motor is in the same position as pole N_1 of the first motor, pole N_7 of the second generator will be in the same position as pole N_1 of the first generator, and the two sets will be in synchronism on both ends. In practical operation, the second motor may be connected to the circuit in any one of five polar positions (considering only one direction of excitation); if the generator poles have different positions, they may be brought into the same position by slipping a motor pole as often as may be necessary.

It will be noted from the preceding discussion that the number of synchronizing positions depends on the number of poles in the motor and generator of the set; that with some pole combinations the number of correct positions is increased by reversing the generator excitation, and in others by reversing the motor excitation. These results may be summarized as follows:—

1—The number of synchronizing positions of the incoming set, with a single direction of excitation in both motor and generator, is the greatest common divisor of the number of *pairs of poles* in motor and generator of the incoming set.

2—The number of synchronizing positions of the incoming set, with both directions of excitation in *both* motor and generator, is the greatest common divisor of the number of *poles* in motor and generator of the incoming set.

3—The number of synchronizing positions of the incoming set, with both directions of excitation in *either* motor or generator, is the greatest common divisor of the number of pairs of poles of the machine with a single direction of excitation and the number of poles of the machine with both directions of excitation.

Whether the installation of a field reversing switch for the motor or generator, or for both, is of any value, may be determined from the rules just given. Thus in the 10 pole-24 pole set, with both directions of excitation for the motor, the number of synchronizing positions is *two* (the greatest common divisor of 10 and 12); with both directions of excitation for the generator, the number of synchronizing positions is *one* (the greatest common divisor of 5 and 24); with both directions of excitation for both generator and motor, the number of synchronizing positions is *two* (the greatest common divisor of 10 and 24). Therefore, a field reversing switch

for the motor is desirable, but a similar switch for the generator is of no benefit.

This information for the pole combinations ordinarily used is given in Table I. This information applies whether the set is started from the low-frequency or from the high-frequency end.

TABLE I—POLAR COMBINATIONS OF FREQUENCY-CHANGER SETS

Motor Poles	Gen. Poles	Direction of Excitation		Syn. Positions			Motor (Low Freq.) Field Switch Req	Gen. (High Freq.) Field Switch Req.
		Motor	Gen.	Motor Alone	Gen. Alone	Set		
4	10	Single Both Single	Single Single Both	2 4 2	5 5 10	1 1 2	No	Yes
8	20	Single Both Single	Single Single Both	4 8 4	10 10 20	2 2 4	No	Yes
10	24	Single Both Single	Single Single Both	5 10 5	12 12 24	1 2 1	Yes	No

MECHANICAL ADJUSTMENT OF TWO FREQUENCY-CHANGER SETS

Before two frequency-changer sets can be safely connected in parallel on both motor and generator ends, the relative location of the field poles and armature winding of one set must be made identical with the relative location of the same parts of the second set, so that when the two motors are properly synchronized as just described the two generators will be in phase. Even in sets of duplicate design, ordinary manufacturing variations usually prevent two sets from being operated together in this way without some adjustment. Obviously, with sets of different sizes and with sets made by different manufacturers, the need for adjustment will be greater. This requirement is met by supporting one frame—usually the motor frame—in a cradle in which the frame can be rotated through a small angle, as shown in Fig. 1.

Frame Adjustment at No-Load—The two sets to be adjusted should be synchronized on the motor ends until the least possible difference exists in the generator phase. If the generator switchboard contains a synchroscope, this adjustment will be greatly facilitated. If any difficulty is experienced in determining the best motor synchronizing position, a systematic study, as outlined below, should be made.

1—Mark a radial line on some accessible part of a motor pole and place a mark on a generator pole that is in line with it, the two marks lying in the same radial plane. It will be found convenient to use the motor pole and the generator pole that are approximately in line, if such exist. Place the rotors of both sets in such positions that the lines on the motor poles are in line with the armature slots containing the terminal coil of the *A* phase. Observe the angular difference, if any, between the mark on the generator pole and the slot containing the terminal coil of the *A* phase of the generator in both sets. If this angular difference is the same in the two sets, no frame adjustment will be required. If it is not the same, the frames of one or both sets will have to be moved to make it the same. An approximate adjustment of the frame can be made from these mechanical measurements, but the final accurate adjustment must be made by operating the two sets. If these mechanical measurements indicate that the two sets are widely different (more than 3 or 4 degrees difference in generator rotor position with respect to the terminal coil) the difference can be reduced by electrical adjustments described later.

2—With one set running with full voltage on the motor and with the generator on open circuit, start the second set, synchronizing the motor with the supply system. Note the synchroscope reading. Cause the second motor to slip a pole by reversing the field excitation and again note the synchroscope reading. (The motor will more readily slip a pole if it is operated on the starting voltage, assuming that the motor is alternating-current self-started, but care should be taken that it is not operated from the starting taps long enough to overheat the starting autotransformers.) Note the reading of the synchroscope for each rotor position of the second motor. It is not necessary to experimentally observe the synchroscope readings with reversed generator excitation, as these will be 180 degrees displaced from the corresponding reading with the original direction of excitation. These should be set down together with the observed readings, and these readings should be compared with the theoretical differences in generator rotor position. Such a set of readings for a 4-pole-10 pole set is given in Table II for purposes of illustration. The theoretical differences in generator rotor position, assuming correct mechanical adjustment, are shown in Table III. Comparing the figures in Tables II and III, it is evident that the second generator is set 10 electrical degrees ahead (i. e., *Fast*, as indicated by the synchroscope) of its correct position, with the motor in No. 2 position. The two generators will be brought into the same polar position if the second motor is synchronized in No. 2 posi-

TABLE II—COMPARISON OF SYNCHROSCOPE POSITIONS FOR DIFFERENT ROTOR POSITIONS

Rotor Position of Second Motor	Actual Difference in Generator Phase by Synchroscope	
	Original Excitation	Reversed Excitation
1	100 deg. Fast	80 deg. Slow
2	10 deg. Fast	170 deg. Slow
3	80 deg. Slow	100 deg. Fast
4	170 deg. Slow	10 deg. Fast

TABLE III—DIFFERENCES IN GENERATOR ROTOR POSITIONS OF A 4 POLE-10 POLE SET

Rotor Position of Second Motor (Rotor Position of First Motor = N_1)	Rotor Position of Second Generator as compared with N_1 of First Gen.	
	Original Excitation	Reversed Excitation
N_1	0 Deg.	180 Deg.
S_1	90 Deg. Behind	90 Deg. Ahead
N_2	180 Deg.	0 Deg.
S_2	90 Deg. Ahead	90 Deg. Ahead

tion and the frame of the second motor is moved ten electrical degrees (two mechanical degrees) in the direction of rotation.*

TABLE IV—THEORETICAL DIFFERENCES IN GENERATOR ROTOR POSITION

For a 10 pole-24 pole set, assuming correct mechanical adjustment.

Rotor Position of Second Motor (Rotor Position of First Motor = N_1)	Rotor Position of Second Generator as compared with N_1 of First Generator	
	Original Excitation	Reversed Excitation
N_1	0 Deg.	180 Deg.
S_1	72 Deg. Behind	108 Deg. Ahead
N_2	144 Deg. Behind	36 Deg. Ahead
S_2	144 Deg. Ahead	36 Deg. Behind
N_3	72 Deg. Ahead	108 Deg. Behind
S_3	0 Deg.	180 Deg.
N_4	72 Deg. Behind	108 Deg. Ahead
S_4	144 Deg. Behind	36 Deg. Ahead
N_5	144 Deg. Ahead	36 Deg. Behind
S_5	72 Deg. Ahead	108 Deg. Behind

3—It is possible, if the two sets are of dissimilar manufacture, for the second generator to be out of phase, when tested as just described, by a larger angle than can be corrected by the maximum frame movement permitted by the cradle. The out-of-phase angle may be reduced in most sets by advancing all motor armature leads (*A* to *C*, *C* to *B* and *B* to *A*) so as to change the motor phase 120 electrical degrees in a three-phase motor, or 90 electrical degrees in a two-phase motor. A change of one electrical degree in the motor phase results in a change of 2.5 degrees in the generator phase in the 4 pole-10 pole set, or a change of 2.4 degrees in the 10 pole-24 pole set. The generator phase can similarly be changed by changing the generator winding 120 degrees or 90 degrees (depending on the number of phases). These changes do no good in the case of a four-pole motor having a two-phase armature winding, for example, or in the case of a six-pole motor having a three-phase winding.

If all the possible electrical adjustments are made, that is, if the motor is synchronized in all possible positions, if the generator field is reversed and if the motor and generator armature leads are interchanged as described, the frequency-changer sets can be synchronized within a very small angle (in mechanical degrees). If, after attempting to adjust two sets, the smallest obtainable generator phase difference is greater than can be corrected by the frame movement provided, further electrical adjustments should be made, making use of the mechanical measurements previously described as a first approximation to the change in phase angle that is required.

The electrical adjustments that can be made are indicated by the following example, showing the maximum frame movement that would be required in a set having a four-pole, three-phase motor and a ten-pole, three-phase generator:—

Assume that one set differs from the other in generator phase to the greatest possible extent. Obviously, it can differ by no more than 180 electrical degrees. However, any difference greater than 90 degrees can be changed to a difference less than 90 degrees by reversing the generator field excitation. If in any synchronizing position of the second motor the generator phase difference is 90 degrees, this can be reduced to zero by making the motor slip a pole. Therefore, any phase difference greater than 45 degrees can be changed to a difference of less than 45 degrees by reversing the motor field excitation. If the motor armature leads are advanced one terminal, the motor phase will be changed 120 degrees, or 300 degrees in generator phase $(120 \times \frac{10}{4})$. If this change be added to the previously existing difference of 45 degrees, there will be a difference of 345 degrees, which is equivalent to a difference (in the opposite direction) of 15 degrees (360 — 345). In this set a change in generator terminals produces the same change in generator phase as does a change in motor terminals. If the motor armature is two-phase, no new combinations can be obtained that could not be obtained by slipping a motor pole, for both changes result in a change of 90 degrees in motor phase.

If no generator synchroscope is available, lamps may be used. Since lamps give no definite indication of the angle of generator phase difference, greater dependence must be placed on the mechanical measurement of generator phase difference. When the generators are nearly in phase they may be connected in parallel and a more accurate adjustment made. The field currents should be adjusted for equal voltages before the generators are connected together, and the field currents should not be changed thereafter. A current will flow in the generator armatures that will be proportional (for small angles) to the phase difference. The frame should be moved slightly and the effect on the current noted. The frame should then be moved in the proper direction until no current flows in the generator circuit. If the field excitation is not correctly adjusted as described above, before the generators are paralleled the armature current cannot be reduced to zero by moving the frame. The current that circulates in the two generator armatures due to phase differences is, however, an energy current—one generator will be acting as a generator supplying power to the other generator, driving it as a motor. The two motors of the frequency-changer sets will, therefore, indicate whether the currents flowing in the generators are due to mechanical phase differences or to differences in field excitation. In the former case, the currents taken by the motors will be much greater than required by the losses of the set, and one motor will be acting as a generator (a wattmeter will show reversed power).

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*The movement of a pole in the direction of rotation advances the phase of the generated voltage and a movement of an armature coil (or frame) in the direction of rotation retards the phase. This is true whether the motor or generator frame is moved to adjust the generator phase.

DIVISION OF LOAD BETWEEN TWO SETS OPERATING IN PARALLEL

If two sets are correctly adjusted mechanically, as has been described, and if they are properly synchronized, they will operate in parallel on both motor and generator ends without cross-currents, assuming that the field excitation is properly adjusted and that there is no load on the generator bus. As load is connected, the load division between the two sets may be proportional to their ratings, or it may not, depending on the comparative design proportions of the two motors.

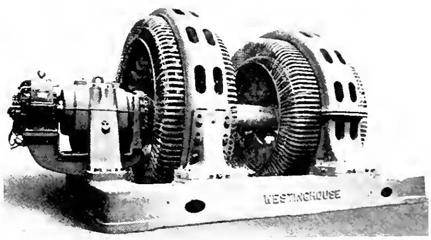

FIG. 6—6825-K.V.A. FREQUENCY-CHANGER SET
With direct-connected exciter.

As a synchronous motor is loaded, the phase of the counter e.m.f. of the motor changes, the phase of the motor e.m.f. dropping behind the line e.m.f. as the load increases. The phase of the line e.m.f. may be visualized as the position of a motor pole (in a two-pole rotating field motor) if the motor carries no load whatsoever; and the phase of the motor e.m.f. may be represented by the position of the *opposite* pole at the various loads applied to the motor, at the time that the same instantaneous value and direction of line e.m.f. exists. As load is applied to the motor, the position of the opposite motor pole will drop behind the position it had with no load at the chosen reference time; and the amount of the difference will be found to increase as the load increases.

This change in motor e.m.f. phase corresponds to the drop in speed, as the load comes on, in a direct-current shunt motor. The synchronous motor drops back, in rotor position, until sufficient armature current flows to carry the load; the action is analogous to the more familiar action of the shunt motor in decreasing its speed until the difference between line voltage and motor voltage (counter e.m.f.) is sufficient to cause a current to flow that will produce the required torque.

If the frequency-changer sets have induction motors, instead of synchronous motors, the load division is determined by the relative slips of the two motors. In this case an actual drop in speed occurs, as in the direct-current motor or engine-driven generator.

While there is a change in phase between the internal e.m.f. and terminal e.m.f. of the generators that increases with load, this does not affect the division of *energy* load between the sets and need not be considered in this connection.

Two sets having synchronous motors will divide the available load in such a way that the angle of motor phase shift, due to the load, will be the same in the two motors. If one motor is designed so that it drops back a smaller angle when carrying its rated load than does the other motor, then the first motor will carry more than its proper share of the load.

If two sets do not satisfactorily share the load, there is no possible adjustment that will improve the load division at all loads. The load division at some particular load, such as rated load, may be improved by advancing the phase of the motor which is carrying less than its proper share of the load, this being done by moving the frame in the cradle. This will increase the load taken by the motor by the same amount at all loads, so that at light loads this motor will take more than its share, and at no load may motorize the generator of the other set. This action is analogous to the action that takes place in two shunt-wound, direct-current generators in parallel when the excitation of one generator is increased to compensate for a greater drop in engine speed.

Synchronizing an Unloaded Set With a Loaded Set—The fact that both the motor counter e.m.f., as compared with the line voltage, and the generator terminal e.m.f., as compared with the generator internal e.m.f., shift in phase, in the same direction (assuming the usual condition of lagging generator current) as the load increases, introduces a new factor in synchronizing a loaded and unloaded set. If the two sets are correctly adjusted for exact synchronism at no load, it will be impossible to exactly synchronize an unloaded set with another set that is transferring power between two systems. It usually will be satisfactory to connect the two generators together, even though exact synchronism does not exist.

In connection with this question of synchronizing an unloaded set with a loaded set, it is interesting to point out that the total shift in phase, due to load, is greater when power is transferred from the low-frequency system to the high-frequency system than when the direction of power flow is reversed. The reason for this is, of course, the fact that the phase shift of the motor, expressed in generator electrical degrees, is the motor electrical angle multiplied by the ratio of the generator poles to the motor poles. This ratio is obviously greater than unity when the motor is the low-frequency ma-

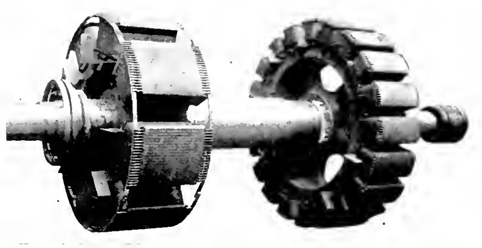

FIG. 7—ROTOR OF A TYPICAL FREQUENCY-CHANGER SET

chine, and less than unity when the motor is the high-frequency machine. In extreme cases of phase shift due to load, this fact might be made of practical use if it happens that when a second set is to be synchronized, the direction of power flow can be made such as to secure this smaller angle of phase shift.

STARTING AND STOPPING FREQUENCY-CHANGER SETS

If a frequency-changer set of the synchronous type ties together two generating systems, the two systems must be synchronized through the frequency changer. This can only be done by changing the speed and frequency of the generators of either primary source of power. Usually the frequency-changer set is located in the same building with the generators of one system, and obviously it will be most convenient to synchronize the set by adjusting the speed of these adjacent generators. This condition applies to induction motor-driven sets as well as to synchronous motor-driven sets. While the speed of a set, driven by an induction motor, having a phase-wound secondary, is under control when the set is transferring power (by changing the resistance in the secondary circuit) the speed cannot be appreciably changed at no-load for synchronizing purposes, on account of the negligible secondary voltage and current then existing.

In starting a second frequency-changer set of the synchronous type, it cannot be exactly synchronized with a set already carrying load, on account of the phase shift in both motor and generator, due to load. The usual practice is to connect the incoming generator to its load in spite of this phase difference, when the incoming generator will automatically take its share of the load.

A similar problem is encountered in starting a second induction motor-driven set when a similar set is already in operation and carrying load. In this case the speed of the unloaded set will be higher than that of the loaded set. The incoming generator may be synchronized with the loaded generator by opening its motor line switch when the speed is above that of the loaded set. The set will then drift down to the speed of the loaded set, and the line switch of the incoming generator may be closed when the two generators are in synchronism. The generator will then be operating as a motor with the induction motor disconnected from its line. With the two generators operating in parallel, the induction motor of the unloaded set will have a forced slip equal to the slip of the loaded induction motor, and when the motor line switch is closed it will tend to take a load corresponding to this slip.

When a synchronous motor-driven set is disconnected from the system to which it is transferring power the load on the set cannot be gradually dropped. It is necessary to open the generator oil switch, immediately transferring the total load to the remaining units. If the set to be disconnected is induction motor-driven, and the induction motor is phase-wound, it is possible to gradually transfer the load from one generator to the others by increasing the secondary resistance of the set about to be shut down.

The Application of Oil Circuit Breakers to a Large Power System

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THE selection of suitable circuit breakers for all points in a large power system having several interconnected generators is a complicated problem, the difficulties increasing with the complexity of the power system.* In a complicated power system the situation must be carefully analyzed to determine exactly what component parts of the system are capable of feeding power into a short-circuit at any particular point, and from this the capacity of the circuit breakers which will be necessary at the various connecting points of the system to open properly any short-circuit which is liable to occur.

As a typical illustration of such a problem, Fig. 1 shows a diagrammatic layout for one of the largest power systems in the country, and the data used in estimating the duty required from the circuit breakers is shown in Table I.

This system consists of two generating stations and two substations containing rotating synchronous apparatus, which is capable of feeding back into a short-circuit on the feeder system. The potential is 11 000 volts between phases, or 6350 volts from any terminal to neutral. In Fig. 1 the generating stations are shown divided into two sections for consideration in the circuit breaker determination, as half of the station designated as a consists of nine 7500 k.v.a. synchronous generators of five percent reactance, while the other half a_1 consists of nine 7500 k.v.a. induction generators, which are neglected in the calculations, as these generators do not maintain their voltage under short-circuit conditions.

The station shown at c consists of one 30 000 k.v.a. synchronous turbogenerator of ten percent reactance feeding bus m through a reactance of five percent at 30 000 k.v.a., marked f. The station at d has four synchronous turbogenerators, each similar to the one in c, and each separately connected to its own bus in the same

*See "Oil Circuit Breakers and Their Application," by Mr. J. B. MacNeill, in the Journal for August, '16, p. 364.

manner as in c. Stations c and d are connected to the tie bus m_1 through the tie-bus reactances e and e_1 of two percent at 30 000 k.v.a. The four 4000 kw rotary converters n and n_1 are connected two in parallel to each substation bus section. The short-circuit points s_1 and s_2 are located inside the substations just behind the busses; s_3 is on the substation cable beyond the main station bus and s_4 is on the tie-line just outside the main station bus m.

TABLE I—CHARACTERISTICS OF APPARATUS

Symbol	Apparatus	Total No.	K.v.a. Total	Phase	Volts	Amperes	Reactance* Ohms	Resistance* Ohms
a	Synchronous Generators	9	67 500	3	11 000	3550	0.09	
a_1	Induction Generators	9	67 500	3	11 000	3550	not considered	
c	Syn. turbogenerator	1	30 000	3	11 000	1575	0.4	
d	Syn. turbogenerators	4	120 000	3	11 000	6300	0.1	
e	Two percent, tie-bus reactance	4	120 000	3	11 000		0.02	
e_1	Two percent, tie-bus reactance	1	30 000	3	11 000		0.08	
f	Five percent, main bus reactance.	1	30 000	3	11 000		0.2	
h	Transformer	1	12 000	3	11 000 to 19 000	1099 632	0.4 1.21	0.15 0.46
b	Tie line, No. 0000 wire, (two in parallel) 18000 feet long.							0.43
g	Tie line, No. 0000 wire, (three in parallel) 4500 feet long.							0.07
i	Tie line, No. 0000 wire, (three in parallel) 18000 feet long. . .							0.29

*All reactances and resistances given per phase.

The effect of the tie-bus reactance in limiting short-circuit currents on the line is seen in that, while each generator can feed a short-circuit on its main bus directly through its generator reactance, still it cannot feed a short-circuit on the bus of another generator without feeding in series through its own tie-bus reactance, the tie-bus reactance of the machine on whose bus the short-circuit exists and through the main bus reactance of the second machine. Thus in case of a short-circuit s_1, Fig. 1, the generator c feeds the short-circuit through main bus reactance f to bus m, and through feeder g to substation bus l. The four turbogenerators at d, each of which is on a separate main bus section similar to m, feeds the short-circuit at s_1 (which is off the bus m of the generator c) in a roundabout fashion through e to m_1 to e_1 to f to m to g and thus to l. The generators at a feed short-circuit s_1 through b to m to g and thus to l. The short-circuit current is then determined as follows:—

Phase voltage $= 6350$ volts.

Impedance from c to $p = 0 + j0.4$.

Impedance from d to $p = 0 + j0.1 + j0.02 + j0.08$.

Resultant impedance from c and d to $p = 0 + j0.133$.

Resultant impedance from c and d to $m = 0 + j0.33$.

Impedance from a to $m = 0.43 + j0.09$.

Resultant impedance from a, c and d in parallel to $m = 0.13 + j0.205$.

Impedance to $s_1 = 0.13 + 0.07 + j0.205 = 0.28$ ohms.

Short-circuit current at $s_1 = 6350 \div 0.28 = 22\,600$ amperes.

Three-phase k.v.a. at $s_1 = 22\,600 \times 6350 \times 3 = 430\,000$.

Any power fed into a short-circuit at s_1 from rotary converters at n will not pass through a circuit breaker located between s_1 and l and should not be considered in selecting a circuit breaker located as shown on diagram.

The rotary converter n_1, however, will feed back into s_1 probably about three times its rated k.v.a., or 25 000 k.v.a., at the time an automatic circuit breaker at s_1 will open, giving a total short-circuit at circuit breaker of 455 000 k.v.a. In a similar manner the short-circuit k.v.a. at $s_2 = 200\,000$, at $s_3 = 500\,000$, at $s_4 = 365\,000$.

In making these calculations the effect of armature reaction in reducing the short-circuit current has been neglected, and on such a large system it is wise to do so, for at points s_1, s_2, s_3 or s_4 a short-circuit will not lower the system voltage very much. For the same reason the addition of a time element to the circuit breaker trip mechanism will not reduce appreciably the duty on the circuit breakers at such points. At s_4 a circuit breaker placed between the short-circuit and m will have to open only the current from c and d and the rotary converters. A circuit breaker located on b beyond s_4 from m will have to open only the current that comes over the tie-line b. Generator resistances and feeder tie-line reactances have been neglected. On systems having large amounts of underground high-voltage cables, the capacitive reactance of the cable must be considered. Recent tests on a 24 000 volt cable system showed that the machine's reactance was practically neutralized by the cable capacitance. To secure adequate protection for feeders, as g, an automatic instantaneous circuit breaker was placed at each end so that a short-circuit at s_1 would be opened by two circuit breakers in series.

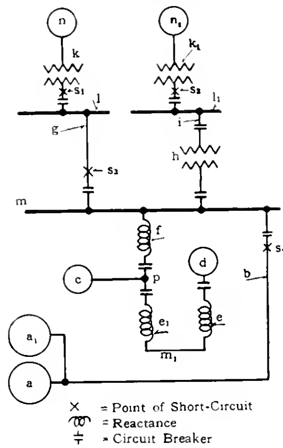

FIG. 1—SCHEMATIC LAYOUT OF A THREE-PHASE POWER SYSTEM

n and n_1 = two 4000 k.v.a. three-phase rotary converters; k and k_1 = two 4000 k.v.a. three-phase transformers; l and l_1 = substation busses; m = main bus; s_1, s_2, s_3 and s_4 = points of short-circuit; a, a_1, c and d are generators; e, e_1 and f are reactances; b, g and i are tie lines.

These values are based on symmetrical generator short-circuits and will be somewhat greater for unsymmetrical ones. However, for short-circuits at points out on the system, the increase of current due to unsymmetrical short-circuits is relatively small.

The Use of Autotransformers on Grounded Neutral Systems

WITH ROTARY CONVERTERS AND MOTORS

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WHEN autotransformers are used with rotary converters on systems having the neutral grounded, particular attention must be paid both to the number of autotransformers used and to the arrangement of taps on the autotransformers.

Normally the taps on an autotransformer are arranged as shown in Fig. 1, in which one terminal is common to both primary and secondary circuits. When autotransformers are used with two-phase rotary converters the taps must be arranged as shown in Fig. 2, in which there are two primary leads *A-A* and two secondary taps *B-B* placed symmetrically with respect to the middle point of the winding.

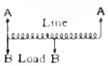

FIG. 1

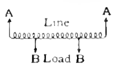

FIG. 2

Fig. 1 — Normal arrangement of autotransformer taps.
Fig. 2 — Symmetrical arrangement of taps.

A rotary converter operating at full voltage from a two-phase line is represented at *1* in Fig. 3 and another rotary converter, being started at reduced voltage from autotransformers, connected to the same line is shown at *2*, Fig. 3. The potential difference between *A* and *B* (Fig. 3) and between *C* and *D* is 100 percent of line voltage, and the potential difference between *A* and *C* and between *B* and *D* is 71 percent of line voltage. In like manner, the potential difference between *a* and *b* and between *c* and *d* is 100 percent of the secondary voltage of the autotransformer, and the potential difference between *a* and *c* and between *b* and *d* is 71 percent of the secondary voltage. Tracing the connections between the two converters back through the bus-bars, it is seen that points *B* and *b* are likewise connected. Therefore, two sources of potential differing in value are connected together, which will cause a sufficient circulating current to flow in the circuit *BDdbB* to make the impedance drop equal to the difference of potential of the two circuits. This circulating current is sufficiently large to be dangerous to the converter windings and connections.

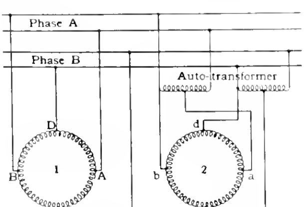

FIG. 3—INCORRECT CONNECTION OF AUTOTRANSFORMERS FOR STARTING A TWO-PHASE ROTARY CONVERTER

If the autotransformers are arranged as shown in Fig. 2 this condition is corrected and the rotary converters will operate satisfactorily, because the neutrals of both rotary converters coincide, and a small portion of the autotransformer winding is interposed between each point on the starting rotary converter and the corresponding point on the running rotary converter. If the generator supplying the two-phase system does not have interconnected windings and no other rotary converter is operating from the circuit, a single rotary converter can be started satisfactorily from the line by the use of autotransformers connected as shown in Fig. 1. But if a second converter be started with this type of autotransformer while another is operating from the line, a large circulating current will be set up which will cause arcing at the brushes on the slip rings of the two machines.

Two autotransformers can be connected in open delta, as shown in Fig. 1, for a three-phase rotary converter, or three autotransformers can be connected in star.

For a six-phase rotary converter, with diametrical connections, three autotransformers arranged as shown in Fig. 2 must be used if six-phase starting is employed. Usually, however, six-phase rotary converters will start on three-phase, in which case two single-phase autotransformers in open delta or three in star may be used as for a three-phase supply.

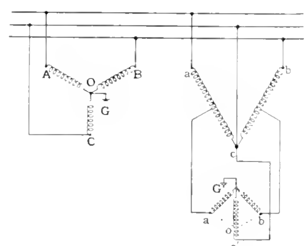

FIG. 4—INCORRECT CONNECTION OF AUTOTRANSFORMERS IN OPEN DELTA FOR STARTING A THREE-PHASE, GROUNDED-NEUTRAL MOTOR FROM A GROUNDED-NEUTRAL SYSTEM

MOTORS

In the case of two-phase motors operating from a grounded neutral system in which the middle points of the two phases are connected both in the system and in the motor, the same conditions apply as in the case of rotary converters, where the autotransformers must be arranged as shown in Fig. 2.

In the case of three-phase motors with grounded neutral operating from a three-phase grounded-neutral line, two autotransformers in open delta cannot be used, because of the unbalancing of the phase voltages which are applied to the motor. The conditions in this case are

indicated in Fig. 4, where *AO, BO* and *CO* represent the windings of the three-phase grounded-neutral generator and *a'G, b'G* and *c'G* represent the windings of the three-phase grounded-neutral motor which is operated from autotransformers in open delta. In this case the generator phase winding *OC* is connected to the motor phase winding *Gc'* through the connection *Cc'* and *GG*. This applies full voltage to the phase *Gc'* of the motor, while the other phases receive reduced voltages *Ga'* and *Gb'* through the autotransformers. It is to be noted also that the voltages in the motor windings are not 120 degrees apart in time phase, as they should be, but about 60 degrees or less, depending on the percentage tap used on the autotransformer. This condition greatly decreases the motor torque and produces a very high current in one phase of the motor. If the ground connection of the motor is opened the motor neutral will shift to *o* and the voltages in the motor windings will be balanced as shown by *oa', ob'* and *oc'*. If the ground connection cannot be broken, however, three autotransformers connected in star should be used.

Promoting Residential Service

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The first commercial incandescent lamp, with an efficiency of seven watts per candle, was considered a wonderful achievement. Successive and rapid evolutions increased the efficiency, as well as the life, of the carbon lamp until it reached 3.1 watts per candle. Then the metallized filament, later the tantalum, and finally the tungsten lamps were brought out, the latter with an efficiency of 1.2 watts per candle. Now the gas-filled lamp has been added, showing a better efficiency yet. Contemporaneously electric lighting developed into a business of amazing proportions. In practically all public utilities the greatest percentage of the customers are yet those using electricity for lighting service. But the remaining percentage includes by far the largest users of current, to such an extent that the income derived from power and other applications in many cases largely exceeds that secured from the lighting business.

Every improvement in the efficiency of lamps results in a reduction in the amount of electrical energy consumed in lighting service. The public is, therefore, the first to reap the benefits of these economical improvements. This reduction is subsequently balanced by more extensive lighting and by the addition of new customers converted to electric service by reason of its greater economy and convenience. However, to supply these new customers requires additional investment in lines and equipment, and, assuming that the lighting revenue is brought back again to the same level as before the advent of more economical lamps, the financial burden of the public utility has considerably increased and the margin of profit decreased.

Obviously, the electric lighting business is more expensive to carry than the power business, due to a greater investment in equipment over a large area, with closer regulation and other requirements, all of which represent a proportional increase in the fixed charges, cost of operation, of maintenance and administration.

On an average the major percentage of lighting customers are in the residential class. Every possible encouragement should be afforded for the development of this class of lighting business, because it brings a more steady income than the commercial class of lighting customer whose business is subject to wide variations following the fluctuations of trade, business conditions, etc. Furthermore, the maximum demands of the residential customers occur generally at periods of light load, and are thus favorable to the economical operation of the central station.

In dealing with this problem, two factors must necessarily be considered; one, and perhaps the most important, is the computing of a rate permitting the residential customer the full use of the electric service, which cannot any more be limited to lighting, but must be extended to make possible the general use of electricity in the home for the more economical performance of useful labors and duties. Upon the equitable settlement of this rate question depends the success of the second factor—the promotion of the general use of electrical appliances.

Very little increase of revenue can be anticipated from lighting, because the tendency will be, as in the past, to produce lamps with a greater illuminating efficiency, and a resultant decrease in energy consumption, which is only partly offset by a greater number of lamps in service. Hence public utilities must look for a compensation in the vast field afforded by the domestic appliances, with the anticipation of productive results that will ultimately exceed all predications, because these applications are unlimited and the demand will always become greater as a palliative to the ever-increasing cost of living.

Under the prevalent rates in the majority of communities for residential service, the customer is afforded very little encouragement in the use of electrical appliances. The utility of these devices is readily appreciated, but they are kept beyond the financial means of the greatest part of residential customers. Commendable steps have been successfully taken in a number of cases in the formulation of rates to remove the prohibitive barrier to the introduction of electrical appliances in the household. Yet these rates, while meeting in a way the immediate needs of the situation, are in the main arbitrary and lack flexibility in their adjustment

to the individual requirements of a varied class of customers.

The rate question seems to be deadlocked—not because of a lack of willingness on the part of the public utilities to squarely confront the problem and attack it with an earnest desire for its solution; neither because the public is refractory to beneficial actions or dislikes electric service; but because of the absence of satisfactory devices to measure correctly the service rendered.

Owing to this present discrepancy, there is no other recourse but to improve a rate by taking as a basis average results with the help of statistical data. On the elementary principle, admitted even by the most biased customer, that any article or product, under penalty of failure of its producer, must bring from its sale all the expenses occurred in its production and up to the point of transfer, plus a reasonable profit; it has been found what the average lighting customer must pay for the maintenance and operation of the channels necessary for the delivery of the electrical energy. On the average this is equal to a sum substantially represented by a consumption of energy equal to the maximum demand for a period of thirty hours and expressed in kilowatt-hours. When this amount has been reached the service can be supplied at practically the total cost of production of the electrical energy at the central station, plus a reasonable profit, together with an allowance for the transmission losses in transit.

The former charge, called a service or demand charge, is manifestly consistent with all laws of trade, and is readily understood; the individual amount of the demand fixing the ratio of the total service charge of that class of customer is yet a factor to be determined and, as stated before, there is no other alternative but to fix it arbitrarily from statistical information, either on an active room basis, on a scale of factors, or any other convenient method, inspired with a view of equitably pro-rating the cost and expenses incurred in the delivery of the electrical energy to the customers. A schedule of rates applied according to this method, while not in the least discriminating in its principle, does discriminate in its application, as it does not recognize individual taste, custom, need or convenience.

In rate making it is essential to consider the business of the public utility as being conducted by two different departments, namely, the production or manufacture of the commodity, and its distribution and delivery to the customers. The character of each one of these departments is so distinct, not only in their operation but also in their requisites, that their respective expenses must be kept separately, as is common practice in every other industry.

At one place the product is manufactured wholesale and delivered, so to speak, at a shipping platform, whence the other department conveys and delivers it to the customers and attends to all the commercial transactions inherent to the business.

It follows that the final charge to the customer must include,—first, the cost of production of the commodity plus a profit, this charge being only slightly affected by the volume of the output; and second, the service charge, covering all expenses incident to the conditioning of the product for its distribution and delivery, together with the commercial expenses of sale, bill collecting, credit, administration and fixed charges, with in addition a profit.

It is evident that the cost of manufacture has no relation to and cannot be affected in the least by the expenses of distribution of the product, these expenses being variable according to the class of customers. Therefore, the logical demand that the final charge or amount to be billed the customer should be determined automatically requires a meter that recognizes not only kilowatt-hours, but also the maximum demand of the customer persisting over a certain period. Under these conditions the customer is not limited to a definite maximum k.v.a. demand, but can exceed this stipulated limit when necessary, the recording device indicating the additional charge incurred. A service based on kilowatt-hours only is just as absurd as a freight rate reckoned on weight only, disregarding the physical nature of the article, distance and speed.

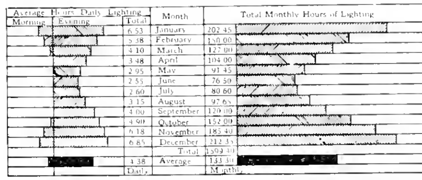


FIG. 1—AVERAGE HOURS OF ARTIFICIAL LIGHTING BY RESIDENTIAL CUSTOMERS PER YEAR

The instrument needed to span the gap between the public utilities and their customers is an "electric service meter," indicating both energy consumption and maximum demand, in a form understandable to the customer, and thus providing the public utility with consistent information for billing purpose. Such a meter will make possible the application of scientific rate schedules, further promoting the use of electricity.

The analysis of practical results obtained in the operation of public utilities indicates that the daily hours of

TABLE I—ANALYSIS OF AVERAGE REQUIREMENTS

1	Customer's symbol.	A	B	C	D	E	F
2	Number of lamps	10	20	40	60	80	100
3	Kw connected load..	0.5	1	2	3	4	5
4	Max. lamps burning.	6	11	20	27	32	35
5	Kw max. demand.	0.30	0.55	1.00	1.35	1.60	1.75
6	Demand factor, percent.....	60	55	50	45	40	35
7	Av. kw-hr. per month	20	40	70	90	110	125
8	Load factor, percent.	5.55	5.55	4.80	4.16	3.82	3.47

artificial lighting vary throughout the year, as shown in Fig. 1, averaging 4.38 hours daily, 133.3 hours per month and a total of 1600 hours of lighting per year.

Classifying residential customers by the number of 50 watt lamps connected, or its equivalent, it is generally found that the demand factor varies inversely with the connected load, approximately as shown in Table I. These customers, if charged on a straight 10 cents per

kw-hr. rate, can hardly afford (especially the small ones) to introduce electrical appliances in their home. But if, for instance, the rate is ten cents for 30 hours' use of the maximum demand, which is given on line 5, and four cents for all energy used in excess (this rate has been reduced as low as one cent in some localities), the average monthly bills for lighting are greatly reduced, as shown in Table II, and the introduction of electrical appliances in the home is made possible.

TABLE II—COMPARISON OF MONTHLY BILLS

Customer's symbol	A	B	C	D	E	F
Demand charge ...	$ .90	1.65	3.00	4.95	4.80	5.25
Energy charge	$ .44	.94	1.60	1.08	2.48	2.90
Total charge	$1.34	2.59	4.60	6.03	7.28	8.15
At 10c per kw-hr	2.00	4.00	7.00	9.00	11.00	12.50

The straight kilowatt-hour charge which was perhaps justified several years ago is now irrational, since progressive developments have adapted electricity to a great diversity of service. Under the modern conditions the central station does not sell any more electrical energy in the form of kilowatt-hours, but it sells rather an electric service always at the command of its customers for any uses and applications deemed convenient. A comparison, as in Fig. 2, of the two rates above named, when applied to the small customer of class *A* (which represents the greatest percentage of the residential customers of most public utilities), shows the absurdity of the straight rate charge.

There is a point on the 10 cent rate curves where a perfect balance exist between it and the total charge for energy and service (inclusive of profit); any consumption beyond this point is overcharged and would soon be out of all proportion if the customer was compelled to a greater use of the commodity. Generally the customer is bound to exercise great care in the use of the electricity and refrain from applications other than

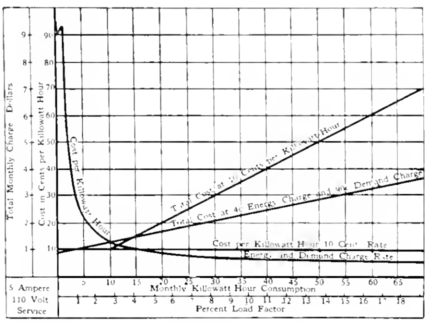


FIG. 2—COMPARISON BETWEEN A TEN-CENT STRAIGHT RATE AND AN ENERGY AND DEMAND RATE

As applied to a 500 watt, connected-load, residential customer.

those strictly necessary, with a consequent degree of annoyance and hindrance to the development of the business.

The demand rate works out in the opposite direction with mutual benefit. The cost per kilowatt-hour consumed decreases with the consumption, the customer actually pays for what he uses, avails himself more freely of the service and, extending it to other applications, improves his load factor, while yet remaining practically within the same maximum demand. The public utility receives a true and just compensation for actual service rendered and secures a greater diversity

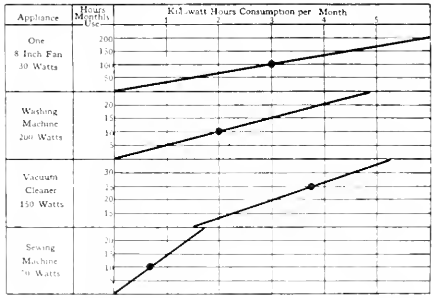


FIG. 3—POWER CONSUMPTION OF TYPICAL DOMESTIC MOTOR APPLIANCES

The dot represents average conditions.

factor, requiring no additional investment or expense, but rather contributing to an increased output of the generating equipment and tending to reduce the cost of production.

Classifying the most popular electrical appliances, together with their respective energy consumption and average hours of use monthly in the household, as indicated by circles in Fig. 3, it is seen that the small customer can afford a flatiron and yet keep his average monthly bill within the 10 cent per kw-hr. rate; that is, on the average use of 30 hours per month of a 550 watts flatiron, the cost at four cents per kw-hr. increases the *A* customer lighting bill 66 cents, or from $1.34 to $2.00, with a probability of his extending his use of electricity to other applications, which may be expected

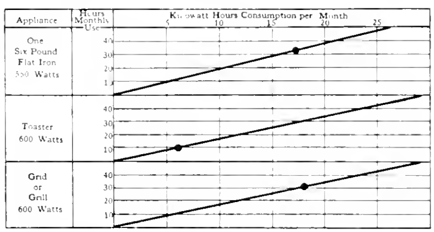


FIG. 4—POWER CONSUMPTION OF TYPICAL DOMESTIC HEATING APPLIANCES

to bring the average monthly bill to $2.50 or even more, corresponding to an increase in the public utility's revenue of 25 percent and, in addition, winning additional consumers through the free and effective advertisement of satisfied customers.

The public utility can fortunately go a step further in promoting the use of its product and again increase its revenue by applying a combination demand and energy rate, as stated above, with a block rate for the

energy charge; as for instance, four cents for the energy consumption up to a certain amount of kilowatt-hours and then two cents for any excess, or other agreeable subdivision of the block rate.

Such a rate opens a wider gate for the introduction of electrical appliances, especially for cooking purposes, a desirable load occurring for the greater part of the year, at a time when a dip starts in the daily load curve at the central station.

It is unnecessary to emphasize the advantages offered to the householder by the ever-growing number of electrical appliances. No doubt a more general application will be made in the future, following the logical adjustment of residential rates, an intricate problem, the solution of which seems complicated when judged from its general appearances, but which, if carefully analysed, will reveal to the rate-maker the key to its answer.

ENGINEERING NOTES

Conducted by R. H. WILLARD

Aim—To connect theory and practice

Self-Starting Converters

One of the simplest methods of starting a synchronous converter is from the alternating-current side. Heavy damper bars are placed on the field poles for the double purpose of making the machine self-starting and of preventing hunting, the action being like that of a squirrel-cage motor. In starting, a low voltage is applied to the converter armature through its slip rings. This creates a rotating magnetic field around the armature just as any polyphase winding will do. This rotating field cutting the damper bars on the pole faces tends to drag the damper bars along with the field, but since the dampers cannot move the reaction turns the armature in the opposite

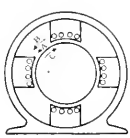


FIG 1

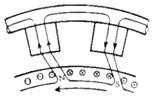


FIG 2

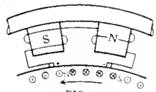


FIG 3

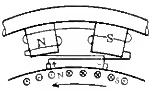


FIG 4

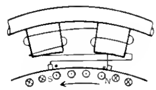


FIG 5

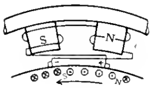


FIG. 6

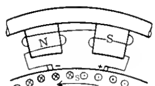


FIG 7

direction at an increasing speed till, when the armature is nearly at synchronous speed, it locks into synchronism because of the salient pole structure of the field.* Fig. 2 shows the current in the armature conductors and the flux path through the field. Since the magnetic field is rotating at synchronous speed with respect to the rotor and the rotor is turning in the opposite direction at synchronous speed, the magnetic field is stationary in space and set just a little back of the field poles because of the drag of the rotor due to friction. The voltmeter will give a small steady deflection positive or negative when synchronous speed is reached. Now let the shunt field switch be closed. If it be closed in the normal running position the converter will drive as a synchronous motor, as shown in Fig. 3. (Use Fleming's rule to determine direction of torque in a motor). If, on the other hand, the field switch be closed in the reverse position conditions will be as in Fig. 4. It will be seen that here a north armature pole is nearly under a north field pole. Since these poles repel, the armature will drop back till the north armature pole comes nearly under the south field pole. When the armature has dropped back to the position of Fig. 5, it will be seen that the brushes are between two conductors, in one of which the current is coming out, in the other going in. In other words, this is the position of zero potential between brushes, so no current will flow and there will be no direct-current field excitation. This will cause the armature to drag back to the position of Fig. 6 due to friction. In this position, although the polarity of the field has changed, the armature has dropped back a pole, so that the resultant torque still is in the direction opposing rotation. If this is followed through for successive armature positions it will be found that the converter will continue to drop back a pole at a time indefinitely. This is what is generally referred to as "slipping a pole." If the above process be followed through for normal field connections it will be found that in whatever position the armature is the resultant torque will assist rotation, hence the converter will drive as a true synchronous motor. Briefly, with normal field connections, the converter runs at synchronous speed; with reversed field connections it runs below synchronous speed and slips a pole repeatedly. It is not necessarily true that the converter polarity is correct even with normal field connections. It will be noticed in Fig. 3 that the right-hand brush is negative. This polarity may or may not be correct for parallel operation. This can be ascertained from the voltmeter. In case it is wrong the field switch is reversed and held till the voltmeter drops to zero, then returned to normal, when it will be found that the machine has slipped a pole and the polarity has reversed, as shown in Fig. 7. If the converter builds up with the right polarity in the first place it will be unnecessary to change the polarity by slipping a pole. When correct polarity is obtained the alternating-current side is connected to the full alternating voltage and the machine is ready to connect to the bus.

The position of the field switch does not determine direct-current polarity, but determines whether the converter will run as a synchronous motor or will continually slip back a pole at a time running as an induction motor. Polarity is determined by the relative position of the coils undergoing commutation with respect to the direct-current wave. Each time the converter slips a pole the direct-current polarity is reversed, so running with reversed field gives low frequency alternating voltage at the direct-current brushes.

*See Engineering Notes on Synchronous Induction Motors, September, 1916.

Bus Clamps

In making connections between copper straps, such as busbars, clamps are frequently used. The natural choice of material for low cost of the clamps would be iron, but it is found that where iron clamps are used on straps carrying alternating current serious heating of the clamps sometimes results from

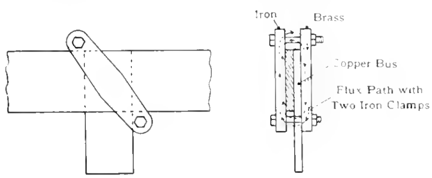


FIG. 1

iron loss due to the alternating flux, which has nearly a closed path around the bus through the iron clamp. To avoid this it is customary to make up the clamps with one brass and one iron piece, as in Fig. 1. Brass, being non-magnetic, does not furnish a closed magnetic circuit around the bus.

Rating of V-Connected Transformers

If the third transformer of a delta-connected group be removed the remaining two will furnish three-phase voltage and will carry a three-phase load. The current for the third phase of the load will be drawn from transformers *1* and *2*. If it is assumed that clockwise direction around the delta is positive the current I_3 in the transformers will be negative. The current I' in transformer *1* will be $I_1 - I_3$, I'' in transformer *2* will be $I_2 - I_3$. Numerically $I' = I'' = \sqrt{3}\, I_1 = \sqrt{3}\, I_2 = \sqrt{3}\, I_3$ if the load is balanced. The k.v.a. rating of each transformer will be $EI' = \sqrt{3}\, EI_1$. The combined rating of the transformers will be $2\sqrt{3}\, EI_1$. The k.v.a. rating of the load will be $3\, EI_1$. The combined transformer rating will be $\frac{2\sqrt{3}}{3}$, or 1.15 times the rating of the load. This means that to carry a 100 k.v.a. load we must have two 67.5 k.v.a. transformers. One way of considering this problem is that in the delta connection the current I_3 only heats one transformer, that in phase *3*, while in the V connection it heats both. This reduces the output of each transformer for the same heating.

Another point of view is to assume the current I in each phase of the load and a voltage E across it. The current in

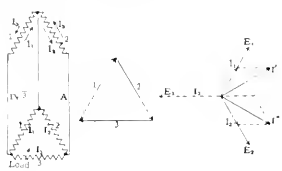


FIG. 1

each line is the resultant of the currents in two phases of the load, which is $I\sqrt{3}$. Each transformer must carry line current, since the only place for the current in line *A* to go is through the transformer. The k.v.a. rating of each transformer will be $\sqrt{3}\, EI$, and the total transformer rating will be twice as much, $2\sqrt{3}\, EI$. The k.v.a. load in each phase will be EI, and the total load three times this value, $3\, EI$. The ratio of total transformer rating to load is $\frac{2\sqrt{3}\, EI}{3\, EI}$, or $\frac{2}{\sqrt{3}} = 1.15$.

Railway Operating Data

Undercutting Commutators

The object of undercutting commutators is to clean out the mica between the copper segments from the face of the commutator to a depth of 3/64 inch. The completed armature, after being rewound, soldered and banded, has the commutator trued up, and all excess solder removed from the neck and face,

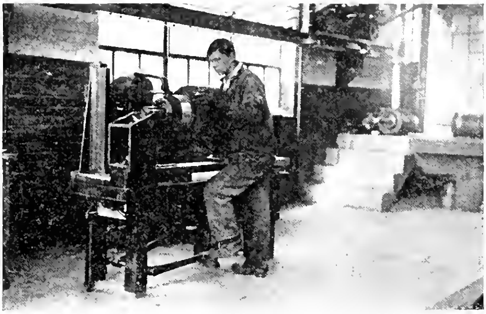


FIG. 1—UNDERCUTTING THE COMMUTATOR
Showing special lathe equipped with a motor-driven saw and operated by foot pedal.

and is then turned over to the undercutter. If undercutting lathes with either motor-driven or belt-driven circular saws, grooves and short-circuit the commutator bars.

TOOLS AND FIXTURES

The most efficient machines for doing this work are special lathes with either motor-driven or power-driven circular saws, clamped on an arbor, which is mounted on a head that moves on slide rails. By means of a hand-operated lever or a foot pedal controlled by the operator, the revolving saw is carried over the

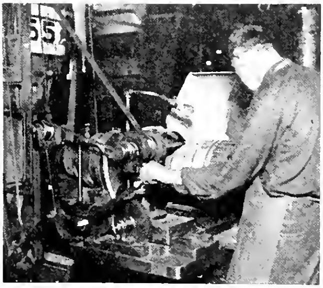


FIG. 2—POWER-DRIVEN SAW
Mounted on lathe head for undercutting commutators.

face of the commutator. The head carrying the arbor is fitted with an adjusting screw to adapt the height of the saw to commutators of different diameter. An air hose and hood is sometimes provided to carry off the mica dust, as shown in Figs. 1 and 2. A less expensive equipment to do this work consists of an air or power-driven (through a flexible shaft) circular saw, which is guided over the commutator face by hand, as in Fig. 3. A hand saw consisting of a piece of hack-saw blade mounted in a holder for doing this work, also a small cutter to clean the slots of small particles of mica left by the circular saws, are also shown in Fig. 3.

METHOD

The armature is mounted between the centers of the special lathe, or on two horses if the hand-guided saws are used, so that it can be rotated readily. The small circular saws are revolved at approximately 2000 r.p.m. and are drawn toward the operator, as shown in Figs. 1 and 2, so that he can guide the cut. The cutting edge of the saw should revolve in a direction toward the operator while it is cutting the mica.

FINISHING

After slotting is completed, the face of the commutator should be thoroughly polished and cleaned of all particles of copper by means of emery cloth. The special lathe can be so equipped that this polishing is done without removing the armature from the lathe centers.

PRECAUTIONS

It is essential that all particles of mica be removed from between the segments by this operation; thus it is advisable to

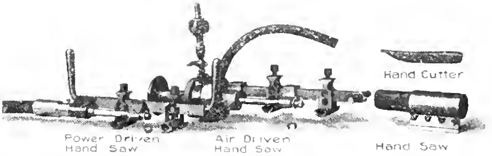


FIG. 3—HAND AND MOTOR-OPERATED TOOLS USED IN UNDERCUTTING

use a saw about 0.005 inch larger than the thickness of the mica to be undercut. A small diameter saw must be used in order to cut the slot to the proper depth and at the same time not cut into the neck of the commutator. After the slots are sawed it is sometimes necessary to go over them with a small hand cutter, Fig. 3, to remove all remaining particles of mica.

ADVANTAGES

A clean undercut commutator prevents high mica, which reduces the burning of the commutator bars, increases the life of the carbon, and practically eliminates flashing. This results in greatly reduced maintenance cost.

REMARKS

An undercut commutator should operate from one heavy inspection period to another. However, if an armature is removed from the motor frame for any other repairs, the commutator should be carefully inspected, and if the mica is getting flush with the copper it should be re-undercut.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1381—Speed Variation of Single-Phase Commutator Motor—I have read with keen interest the article on single-phase commutator motors by Hellmund and Dobson in the JOURNAL for March, 1916. One or two such articles as this make the whole year's issue of the JOURNAL well worth its price. On page 118 the authors describe a system of using two types of connections for the purpose of shifting the torque field from one of the circuits to the other. They say, "This is especially advantageous with motors that have to operate over a large range of speed. It is thus quite logical to operate a motor reverse doubly fed below synchronous speed, stator fed around synchronous speed, and doubly fed over synchronous speed." Can you tell me whether such motors have a smooth variation in speed from lowest to highest, and if so, how this is accomplished, or whether there are simply three steps—low, medium and high speeds—depending upon the connection? G. O. W. (CALIF.)

By connecting the motor to the transformer in the manner shown in the article, it is possible to make the transition from reverse doubly fed to stator fed, and then to doubly fed, with very smooth variations in rotor speed and with no interruptions in the power supply. By the use of a sufficient number of transformer taps, and a sufficient number of switches, it is possible to make the changes in speed as low as desired. A study of the sketch will show the feasibility of securing any number of steps on each of the three motor connections. For the purpose of simplicity preventive coils (used to prevent short-circuits on the transformer windings) have been omitted from the diagram. R. E. H.

1382—Rewinding Motors—I have read the article by Mr. A. M. Dudley in the Feb., 1916 issue, but desire to ask further about a motor having 72 coils span 1—13, four coils connected in series to one pole group. This motor, we will say, is a six-pole machine, the synchronous speed being 1200 r.p.m. If we change the speed of this motor from 1200 to 900 r.p.m., which would require an eight-pole machine, these coils would have to span 1—10, but with the present coils this would be too great a span. If I wish to reconnect a motor, and in doing so should find that the bottom coil in a slot the current goes one way, and in the top coil it goes the other way, I should think that the current would neutralize each coil when they are not going in the same direction. I do not quite understand the connection you would have to make in each pole this way, or if you would have to rewind the motor complete with different pitch coils. Also explain how to get the pitch of a pole or coil this way in winding. E. M. D. (WASH.)

Assuming the conditions given, if a machine were connected as in Fig. 1382(a) and developed 10 horse-power at 440 volts and six poles, and if it be then reconnected for eight poles, as in Fig. 1382(b), with the same coil throw, it should develop about 7.5 horse-power with 286 volts applied. The normal voltage changes from 440 on six poles to 286 volts on eight poles, to keep the same magnetic density in the iron in the teeth. This reduction is due to two factors:—First, running the motor at a slower speed generates less counter electromotive force, and second, the coils have a different throw in times of full pitch, which means a different chord factor or voltage factor, as explained in the article referred to in the February JOURNAL. It is not clear just what is

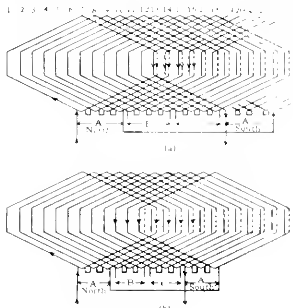


FIG. 1382 (a) and (b)

meant by currents in the opposite direction in the same slots. Considering phase *A* alone and remembering that alternate polar groups are connected in the opposite direction or alternating north or south, it may be seen that the arrows representing current directions in slots *13*, *14*, *15* and *16* in Fig. 1382(a) and slots *10*, *11*, *12*, *13*, *14* and *15* in Fig. 1382(b) are all in the same direction. In considering the other phases *B* and *C* also in connection with *A* it must be remembered that the current varies not only in direction, but also in time, so that while the current in a given coil in the top of a slot might be in phase *A* and seem to be in the opposite direction from the coil in the bottom as the slot in phase *B*, as, for example, slot *13* in Fig. 1382(b), it must be remembered that the current may be rising in one and falling in the other, so that the magnetic result is what it should be. A. M. D.

1383—Measuring Starting Torque—In considering the application of individual motor drive to machine tools at present belt driven from line shafting it is proposed to operate each machine with either a 20, 10 or 5 horse-power, three-phase, 60 cycle, 220 volt induction motor, taking readings of kilowatts, amperes, volts and speed, and by use of the performance curves of each motor to obtain the actual power taken by each machine, together with the running and maximum torque. Will you please advise a practical and accurate method of obtaining the starting torque of each machine? Would good results be obtained by fastening a rod of known length to the countershaft of each machine and adding weights to the end of rod until the shaft just commenced to move? W. P. B. (TENN.)

The method described is the one generally used and gives good results when using precautions not to introduce unnecessary bearing friction due to the added weight and lever. If the motor is belted or geared the pounds torque required for starting is affected by the ratio of the pulley diameters or gears. If the motor is direct-connected through coupling the starting torque required will be somewhat less than if geared or belted, due to the elimination of the side pull on the bearings. A. M. D.

1384—Spark Plug Intensifier—In the *Electrical World* of May 6, 1916, p. 1063, occurs a description of a spark plug intensifier which is supposed to produce "hotter explosions," at the same time operating as an indicator for this spark. As this adds an additional spark gap to the circuit, it is not clear why an intensified action should be secured, although I have been informed by others that this is the fact. Can the reason be briefly explained? O. P. L. (VA.)

If the spark plug in the engine cylinder is clean and free from carbon, a series gap in the high-tension circuit causes a reduced spark action, because the amount of energy in the spark coil is limited to a definite amount, and this energy is then dissipated in two gaps instead of one; furthermore, the voltage may not be sufficient to jump both gaps, in which case no spark would be produced. If, however, the spark plug is sooty or carbonized, it may happen that the leakage path over the dirty surface of the spark plug will short-circuit so much of the current that only a feeble spark will be produced at the plug. In this case the addition of a series gap is often an advantage. The rise of voltage in the secondary is not absolutely instantaneous, but requires a small fraction of a second to attain its maximum. The interposition of a series gap prevents the voltage from jumping the main spark plug until it has nearly attained its maximum value, thus furnishing a much more disruptive discharge, which will pass across the spark plug gap instead of leaking over a carbonized surface. The reference made in your query evidently deals with this latter condition, in which case the claims it makes are true. It might be pointed out that the best remedy for a carbonized plug is to clean the plug. If the plugs persist in

fouling the above expedient will often be an advantage. Most automobile manufacturers now strive to equip their cars with plugs which do not foul, therefore they seldom recommend a series gap. H. V. S. T.

1385—Motor Operation—I have a 125 horse-power motor direct connected to a three-stage centrifugal pump. What effect upon the windings, also the operating of the motor, has the connection shown below in diagram? I realize the coils in phase *B* are reversed. The motor has been giving no trouble as wound, but we can hear an unsteady hum while the motor is running, which may be a distress signal, although I am not certain, not being as familiar with motor characteristics as a motor engineer. F. L. O. (ARK.)

We infer that this winding is similar to Fig. 1 on page 86 of the JOURNAL for February, 1916. If it is and is connected up according to Fig. 1385(a), we should expect it to overheat immediately, even running light, because the phase angle between the voltages generated in the three phases is 60 degrees instead of 120 degrees, as shown in Figs. 1385(b) and (c). We judge, however, that the motor is actually operating under some load. We would suggest that you take a reading of the current in the three phases

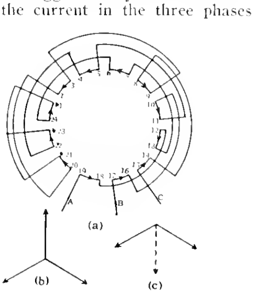


FIG. 1385 (a), (b) and (c)

and see how much they are unbalanced; then reconnect the *B* phase properly, using the end that is now on the star for a lead and the present lead connected to the star connection; then take a reading of the current in the three phases and see if it balances up properly. It may be your transformer connections are also abnormal and the two things have a tendency to correct each other. We believe, however, that if you reconnect the motor as suggested above, the operation will be much improved, and we are greatly surprised that the motor does not overheat with its present connection. In a normal machine the vectors representing the voltage generated in each phase by the rotating field are 120 degrees apart, as shown in Fig. 1385(b). In the machine as you show it with one phase reversed the voltages would be 60 degrees apart, as shown in Fig. 1385(c), and this would cause serious unbalanced currents to flow in the rotor. A. M. D.

1386—Induction Motor Starting Torque—I have a 50 horse-power induction motor that I have built over, putting on heavier end rings. This takes a heavy current in starting and the highest voltage taps are connected to the starting coils. I wish to know if I should wind another set of transformer coils of the same size wire and bring out a tap closer to the end of the coil, say a 90 percent tap, would I get a stronger starting current, or if I should use a larger wire on the coil? E. M. D. (WASH.)

In general, if more starting torque is required, it would be wrong procedure to put on a ring of larger cross section having the same conductivity, since this action would reduce the secondary resistance, and hence probably reduce the starting torque. If the old rings gave trouble due to heating, and it was necessary to increase the section for mechanical reasons, a brass alloy should be used having a higher resistance than the original metal, thus giving at the same time a greater mass of material to absorb heat and a higher resistance to increase the starting torque and decrease the starting current. If the amount of starting current is not objectionable the starting voltage may be increased so long as the motor is not injured, and the starting torque will increase as the square of the applied voltage. A. M. D.

1387—Motors in Parallel—I have two 30 horse-power, 230 volt, series-wound, commutating-pole motors in parallel on a charging crane bridge; they will not divide the load; one motor will take on starting about 70 amperes and fall to zero, the other will rise to 180 amperes; these motors are on each bridge girder, each having a separate line shaft; the gearing and bearings are, of course, alike. I have operated other motors on like jobs successfully, but cannot make these divide the load; I have tried inserting and taking out wire to each motor, and equalizing the conditions as far as size and length of wire to each motor. I am sure the trouble is that the resistance is unbalanced, but I cannot think of any scheme sensitive enough to adjust it. Can you suggest anything? C. C. M'I. (OHIO)

It is understood that in the above case the two armatures are rigidly connected mechanically through gearing or by the bridge wheels and track. The difficulty mentioned will probably be found to be due to the scheme of connections or an error in connecting the motors or controller. If the series field of one motor is connected in series with the armature of the other motor, and vice versa, an unstable condition obtains in which it will be impossible to secure proper load division. If an equalizer is used to connect the two motors at points between the armature and fields the unstable condition is eliminated, but the load balance may still be very unsatisfactory; there may be enough difference between the speed characteristics of the two motors so that one of the motors will carry all the load and, in fact, one motor may even be operating as a generator being driven by the other motor. The simplest order of connections should be employed, each armature connected in series with its own series field and no equalizer connection used. The series windings should preferably be both on the same side of the armatures, i. e., both on the positive or both on the negative side, and on the ungrounded side of the armatures if it is a grounded system. The case of paralleling series motors is much easier than with either compound-wound or shunt-wound motors. If, therefore, the connections are made as outlined above there should be no difficulty in obtaining a satisfactory load balance. It is seldom that two motors will exactly divide the load, because there are few cases in which the speed curves of the two motors will exactly coincide. However, the difference existing should not exceed a small percentage of the average load. The balance of currents can always be improved by slightly shunting the field of that motor which tends to take the lighter load (this in general is undesirable unless an inductive shunt is used); or the improvement may be obtained by inserting resistance in series with that motor which tends to take the heavier load,—but in either of these methods the currents would be balanced for one particular load setting only, and as the load changes the exact balance would probably be destroyed. F. A. R.

1388—Starting a Rotary Converter—One of our substation operators had his arm and hand burned when pulling out the induction motor switch after having thrown in the alternating-current machine switch and pulled out the synchronizing resistance switch. This starting motor is used with a 750 kw, three-phase, 25 cycle, 600 volt, 1250 ampere rotary converter. This has occurred but twice in our experience with this 750 kw rotary and with one of our 500 kw rotaries. H. F. V. (N. Y.)

With a four-pole starting motor and a six-pole rotary converter, the synchronous speed of the converter is considerably below the normal speed of the induction motor. Therefore, once the converter is synchronized, and the main alternating-current supply line switch closed, whether the synchronizing resist-

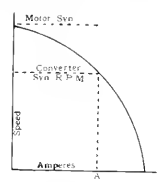


FIG. 1388(a)

ance is in or not, the same current *A* will be required by the induction motor as long as the converter rotates at synchronous speed, as shown in Fig. 1388(a). It is this current, therefore, corresponding to the speed at which the induction motor is made to run, by the rotary being locked in synchronism, that causes the flash. F. D. N.

1389—Voltage Fluctuations—The voltage fluctuation of our power system is very great and we have in operation an alternating-current generator running as a synchronous condenser. This machine is used for power-factor correction only. I wish to know that if by adding a comparatively heavy balance wheel to this condenser whether or not the voltage regulation of the system would be improved. W. C. (OKLA.)

The addition of a flywheel would not affect the voltage fluctuations and would tend to make the condenser hunt. One way in which the fluctuations can be reduced is by the installation of an automatic voltage regulator which controls the full excitation of the alternating-current or of the synchronous condenser. A. A. T.

1390—Reconnection—Referring to the article in the February number by Mr. A. M. Dudley on "Reconnecting Induction Motors," I tried to apply Fig. 15 to a 5 hp, three-phase, 60 cycle, 440 volt motor. The stator was wound for eight poles and connected in series star. I wished only one speed, so I just reversed alternate pole groups in each phase, making them all like poles. The motor furnishes no torque at all at 440 volts, the rotor coasting either direction from a start by hand while the stator was drawing 100 amperes. Does this only apply where the poles per phase have a spacing of 90 mechanical degrees or a four-pole winding? C. E. H. (NEVADA)

The trouble here is due to not reversing the middle phase at the time the reconnection was made. The result is that there is now a 60 degree instead of a 120

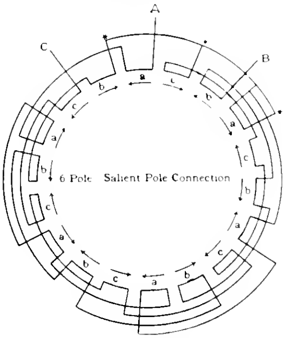


FIG. 1390(a)

degree relation. The number of poles is not given, but assuming that it is six, the diagram "before" and "after" is given in Figs. 1390 (a) and (b). It will be seen that the B phase should be reversed so that the end that was on the star point becomes the lead in the reconnection and vice versa. Attention is called to this fact on p. 87 of the article referred to, in the right-hand column near the bottom, beginning "there is but one exception," etc. According to this statement, if the

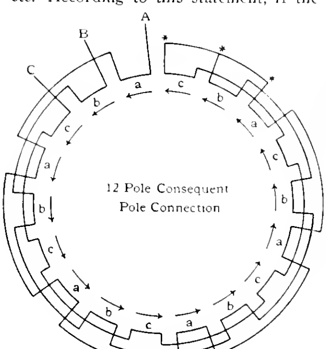


FIG. 1390(b)

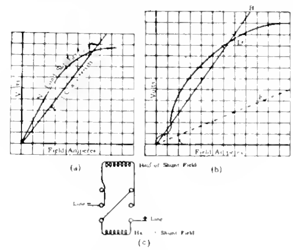
current is assumed flowing in all three leads on a consequent pole connection the arrows on the groups should all point in the same direction, as shown in the 12 pole sketch, Fig. 1390(b). If one phase of the winding as reconnected is reversed, as shown, the motor will operate with the effect of having $\frac{1}{0.866} = 115$ percent normal voltage impressed on it, *plus* whatever overvoltage is caused by the fact that the coil throw is now a different percent of the new or 12 pole pitch, as described under chord factor on pp. 92 and 93, and also in the example on p. 97 of the article. If the change in chord factor adds very much to the 15 percent overvoltage mentioned the motor may overheat, due to iron loss, as any motor would with 20 percent to 25 percent overvoltage. The factor $\frac{1}{0.866}$ is due to the fact that the coils for a 12 pole connection are spread over a 6 pole arc, as mentioned on p. 91 in describing Fig. 18. A. M. D.

1391—Battery Charging Generator—We have a small generator for charging storage batteries which is giving trouble that so far we have been unable to locate. The machine is compound-wound, short shunt connected, bipolar, volts approximately six, amperes approximately 15. It does not generate, but will run as a motor, though it develops no power when doing so. Before being brought to us the armature had been rewound. The brushes were not on the neutral point and, as they are stationary, we changed the commutator leads. After doing this the machine would run as a motor, but did not generate. Changing the commutator leads in the other direction simply reversed the rotation. We tried to magnetize the shunt field, as we believed it to have its residual magnetism, but without effect. The construction of the machine is such that we cannot give it separate excitation while it is running without making some changes in the wiring. J. F. B. M. (IND.)

In self-excited, low-voltage generators, trouble in getting the generator to build up may be caused by high-contact resistance of brushes. If the contact resistance is appreciable it may prevent a sufficiently large current from flowing in the field windings to bring the excitation up to the proper value. In such cases the generator may be made to build up by bringing up the speed. If the generator was connected across the battery, however, the trouble would probably not be caused by high-brush resistance, as the battery voltage would supply excitation. There is also a possibility that the field circuit may be broken. With the brushes displaced from neutral, a sufficiently large torque may be developed to run the machine as a motor at no load, the field being excited by the demagnetizing ampere-turns of the armature. The torque would be too weak, however, to develop any power as stated in the question. As the armature has been rewound, it is, of course, possible that wrong connections have been made. K. L. H.

1392—Building Up Voltage—A 1.5 kw generator of an early date was turned over to me without any field coils. The armature was of the drum type, 80 volts, 1100 r.p.m., shunt wound, direct current. The coils were rewound with No. 19 B. & S. wire. Total resistance of both coils about 46 ohms, 175 amperes, approximately 5500 ampere turns. The machine refused to generate. When separately excited it would maintain voltage satisfactorily and, by using a double-throw switch and throwing the switch over quickly so that potential did not drop below 30 volts, would pick up and maintain itself satisfactorily; yet under no circumstances could it be gotten to excite itself sufficiently to rise over five volts. A. R. R. (MD.)

A self-exciting generator cannot build up voltage if its shunt field resistance is higher than a certain critical value. This may be determined graphically by drawing two curves—the no-load saturation, and the field characteristic, or the relation between the shunt field current and shunt voltage. Typical curves of this kind are shown in Fig. 1392(a). The general rule may be stated that a generator may be self-excited up to that voltage, where the field characteristic first intersects the no-load saturation curve. Due to magnetic peculiarities in iron at low densities, some saturation curves have a slight cusp in them, especially at the low-voltage end. A typical saturation curve having this peculiarity is shown in Fig. 1392(b). If the field characteristic B is in position shown it will intersect the curve at two points, C and D. This machine, self-exciting,



FIGS. 1392 (a), (b) and (c)

may build up voltage only to the point C, but if separately excited, up to a point somewhat above this cusp, it may be quickly switched over to self-excitation, and will continue to be a stable, self-excited generator up to the point D. If this is the trouble in this case it may possibly be remedied by changing the slope of the field characteristic, as at E, so that it will not intersect the saturation curve at any low point. It is suggested that the shunt field coils be connected in two parallels. They will require the use of a rheostat in the shunt field circuit, which should be cut out during starting. By the use of a D.P.D.T. switch, as shown in Fig. 1392(c), the fields may be paralleled at starting and thrown in series for running, thus eliminating a rheostat. F. T. H.

CORRECTIONS

In the JOURNAL for June, '16, p. 316, Table I, last column, first line, the number "21.0" should read "31.0."

On p. 389, Aug., '16, the first formula in the second paragraph should read

$$Surface = \frac{\pi}{2}\,(2\,DL + D^2)$$

In the third paragraph the second equation should read

$$Surface\ per\ hp = \frac{\pi}{2K}\left(\frac{2\,DL + D^2}{D^2L}\right)$$

In the answer to No. 1358, section (b), "ratio of stream diameter to wheel diameter" should read "ratio of wheel diameter to stream diameter." In the third line of section (c) "impulse" should read "reaction."

FINANCIAL SECTION

GROWING IN EARNING POWER

Figures from the electric light and power companies of the country for the opening months of the second half of the year indicate that the revenues of these companies will be larger and show greater gains than did the first half of the year. In the first half these companies broke all former records both in total revenues and increases of earnings and output, and the reports now coming in show most clearly that the last six months of 1916 will be greater in earning power for the central station companies than the first six months. One of the favorable features of the year in the field of electric utility corporations is the much better earnings being shown by the electric railways. These companies are now getting back into a better revenue-producing position, and for the first half of 1916 there was an average gain of over 8 percent in gross and of over 12 percent in net. Figures so far received for the first months of the second half of the year indicate that revenues are now growing at more than 9.5 percent in gross and more than 17 percent in net.

The central station companies are showing much larger increases than the electric railway companies, and for the first months of the second half of 1916 revenues have been increasing at an average rate of close to 20 percent, with some companies going much higher than this. Reports show that the domestic and commercial lighting business is running above the normal increase, while the power business is taxing the facilities of the companies. The growth of the electric power business in the last 18 months has been the greatest in the history of the industry. The tremendous demand made on the manufacturing facilities of the country gave the central station companies an opportunity they had long been awaiting. Previous to that time the companies had had much difficulty in securing the adoption of central station power by the large industrial corporations of the country. Many of these had their steam power plants and would not listen to the displacement of these by central station power. Here and there a company adopted electric power, but progress was slow.

Mr. Samuel Insull, of the Commonwealth Edison Company, probably made greater progress along the line of selling industrial power than any other central station manager or company, but even there it was only slowly that existing industrial power plants were being displaced for the central station energy. About 18 months ago, when the great demand on the industrial plants of the country began to reach its height, there was a change. The industrial plants found that if they were to take advantage of the large amount of new business offering they would have to increase manufacturing facilities, and this, of course, meant enlarging their power facilities. To add to their steam power plants would take a long period of time, and in addition they soon found that the boiler and engine manufacturers were just as busy as they were and that it would require months to secure the filling of orders for additional power equipment. In their extremity they turned to the central stations and asked them to help out by furnishing the power. It did not take long to run a transmission line to an industrial plant and a long period was not required to install the motors. As a result central station energy became popular almost at once with the manufacturers, and the call for motors was so great that the manufacturing facilities of the electric companies were overtaxed. Today in almost every manufacturing center of the country the central station company is now delivering all its available energy to industrial establishments and could largely increase its load could it secure additional generating machinery, but the manufacturers of generating equipment are now also far behind in orders.

One central station company located in an industrial district began last fall to double its generating capacity and completed the additions this spring. It is now in the market for a 20 000 horsepower generator to add to its station, which is already overloaded. Another central station company is reporting an increase of 50 percent in output of its stations over a year ago and, as it cannot secure additional generating equipment at present, is building a transmission line to make connection with an hydroelectric plant from which it will secure energy to tide it over until it can enlarge its own plants. The manager of

FINANCIAL SECTION

a central station company in a central western city, who has been endeavoring to place an order for rapid delivery of additional generating equipment, states that there is 40 000 horse-power of new industrial business waiting until he can have available the additional generating capacity to make it safe to attach this business to his lines. Another central station company began construction last winter of a 60 000 kilowatt station and within three months had decided to increase it to 90 000 kilowatts, and the board of directors is already making plans to add a fourth 30 000 kilowatt unit, although the station will not be delivering its first current until after the first of the year.

These examples of the great demand which has been made, and is being made, on the central station companies of the country could be continued at length, but these few are sufficient to show why the output of the central stations of the country is averaging more than 25 percent above that of a year ago. The electric steel industry is taking a large amount of current, and one hydroelectric station in the south is now doubling its capacity to supply energy to a large plant which is putting in three electric furnaces for steel making and planning to increase this number to ten furnaces in the near future. This wonderful growth in earning power has been having its effect on the securities of the central station companies, and many of them in the last few months have reached new high records in price. In the bond market the bonds of these companies have been growing rapidly in favor and the large bond houses are now eager bidders for issues of central station bonds. The prices of these bonds on an average are materially higher than a year ago, although other classes of bonds are in some instances selling at lower prices, and in others have advanced but slightly. The large gain in earning power has so increased the margin of safety on central station bonds as a class that they now occupy almost a unique position in the market. For a time there was a fear that these large earnings would not continue, but that they would recede with a decline in the industrial activity of the country, but the officials of central station companies have convinced bankers that, instead of decreasing at any time, this earning power will continue to increase indefinitely.

The great diversity of industrial business being taken by the companies and the large gains in earnings from domestic and commercial light and power sources make certain that, while the rate of increase may decline, the actual cash earnings certainly will continue to show gains over a long period yet to come. The companies have a firm foundation in their domestic and commercial business and, with the growing power business added to this, there is no class of corporations in the country with greater possibilities from a revenue-producing viewpoint over a long period of years. The stocks of a large number of these companies have shown a large enhancement in market price over the last year. Cities Service common and preferred, Columbia Gas & Electric Company stock, Northern States Power Company common and preferred, Standard Gas & Electric preferred and common, Southern California Edison common and preferred, Pacific Gas & Electric common and preferred, and many others have advanced anywhere from five to one hundred dollars a share in the last year.

To the man who believes in the future of the central station industry of the country, and no man who has made any study of its possibilities can fail to believe in it, there can be no better investment than a deversified purchase of the bonds and stocks of these electric light and power companies. There are a number of these stocks which are yet selling at a low price and which have just as great possibilities of enhancement in market value as those which have been named. By judicious purchases a diversity of location of issuing companies may be secured which will insure against the future, as it is impossible that there will ever be a situation arise which will affect the earnings of all the companies of the country. By the purchase of the securities of the well-managed and well-financed electric light and power holding companies, this diversity may be obtained while holding the securities of but one company, and this plan probably would be better for the average investor. The holding company securities have the broader market and, where the operated properties have been properly selected, a diversity of location is secured which can be obtained in no other way.

INCREASE IN ELECTRIC RAILWAY REVENUES

Statistics gathered by the American Electric Railway Association from the electric railways of the country for the first six months of 1916 indicated a noticeable improvement in the revenues of these companies compared with the first six months of 1915. Data for the first half of 1916 indicated an average increase in operating revenues of 8.08 percent, in operating expenses of 5.08 percent, and in net operating revenues of 12.10 percent. The figures also showed an average increase in taxes of 6.58 percent and in total income of 13.09 percent. The number of revenue and transfer passengers carried by the companies made an average gain of 7.21 percent, while the revenue car mileage increased 3.32 percent. Electric railways in the eastern district of the country showed an average gain of 9.61 percent in operating revenues, of 6.78 percent in operating expenses and of 14.22 percent in net, while taxes increased an average of 7.01 percent, and total income 15.78 percent.

In the southern district operating revenues made an average gain of 7.18 percent, operating expenses of 1.83 percent and net of 15.82 percent, with an average increase in taxes of 0.52 percent and in total income of 12.53 percent. The western district showed an average gain of 3.07 percent in operating revenue, of 3.45 percent in operating expenses and of 4.04 percent in net.

AMERICA'S ELECTRICAL WEEK

Every central station, manufacturer, jobber, contractor and dealer is continually working for more customers, which is another way of saying producing more sales and thus earning more profits. "More Customers, More Sales, More Profits" is the title of a new book just from the "America's Electrical Week" headquarters. This book is an important contribution to the industry and presents new sales ideas and suggestions. The information given has been gleaned from the work of men in California, in Florida, in Maine, in Indiana, from men in every section of the United States, men who have faced many and varied sales problems and solved them successfully.

It tells of the budget of printed matter that will be used for "America's Electrical Week"—the 6 000 000 pieces of printed matter, the 3 000 000 poster stamps, the 2 000 000 circulars that will be distributed, the car cards, the store signs, pennants and eight-sheet posters. Besides all this, four of the largest and most influential magazines in the country will publish special issues for "America's Electrical Week," telling the people what electricity will do and how to do things electrically. How many millions will see these evidences of activity can only be guessed; that practically every household in the United States will be reached several times cannot be questioned.

Co-operation of the various interests is first discussed: Work together. Work all the time. Preach the gospel that "America's Electrical Week" is not merely for the electrical industry. It is everybody's week. Everybody benefits by electricity. Everybody should celebrate. The plans are built on the successes of last year. Read "The Story of the Week" for your inspiration; then cooperate. It is not telling the people once about "America's Electrical Week," but hundreds of times, that wins their enthusiasm and, therefore, sales.

The book tells how to do missionary work. The advance publicity that has been done makes this work easy and the results sure. Manufacturers, representatives, agents and all those electrical men traveling from place to place are the "advance agents" of the week. They can help by co-operating and doing missionary work, arouse boundless enthusiasm by carrying ideas from one place to another. Optimism about "America's Electrical Week" now, in the preliminary stages of the campaign, is what is needed.

Following the outline of what everybody can do to help make the week a grand success, a section of the book is devoted to what central stations can do to profit from "America's Electrical Week." Almost regardless of what may be accomplished by others in the electrical industry, the central station receives its share. Therefore central stations should make sure that the entire local electrical fraternity is enthused and working. Chambers of commerce, boards of trade, Jovians, civic and fraternal associations and public officials should be urged to participate actively.

This is a good time to urge the selection of a slogan for your city, to promote white way lighting and improved street illumination, and merchants will want special lighting effects and displays. Patriotism is running high and flashing flags should be in demand. Public buildings, statues and points of interest can be flood lighted.

Central stations can make excellent use of the special publicity material which is being issued. The official poster is especially attractive and can be used with telling effect. How to use form letters, demonstrations, plans for window displays, suggestions for newspaper and street car advertising and contests are given in this book. Electric shows and special days during the week are mentioned and plans suggested.

The third section is devoted to what electrical dealers and contractors can do to cash in on "America's Electrical Week." The opportunity is most propitious because of the extreme activity of the other branches of the electrical industry, and it only needs a similar activity for the dealers and contractors to get their share. First, they should co-operate with the other interests and get in touch with the local committee having the plans for the week in charge. Only by co-operation can each interest, at least expense, get its full share of the increased business that will be developed. Attend the joint meetings of the electrical interests in your town and work with the others.

The Society for Electrical Development outlines, in this book, the assistance it is prepared to give dealers and contractors; window displays, for their own use and to be sold to merchants, form letters to prospective customers, store displays and demonstrations, and special work to turn the Christmas buying that begins at the time of the week toward electrical devices. The advertising value of electric light must not be overlooked. A campaign for electric flashing flags is suggested.

Plans for enthusing employes are given. There is something that each one can do to help make this week the most memorable event in the industrial life of America, as well as the greatest business booster that the electrical industry has ever seen. Mr. Dealer and Mr. Contractor, this is your week, your opportunity to cash in not only on the work you do, but on the work that thousands of other electrical Americans will do.

Many of the suggestions for the central stations and dealers and contractors are also applicable to the manufacturer and jobber. Nevertheless, the last section of the book is devoted to the work that these interests may do to cash in on "America's Electrical Week." Attention is called to the fact that the week is the contact point between the two poles of distribution—selling and advertising.

Manufacturers and jobbers must sell the week to their salesmen and to their advertising departments. The official poster shows Aladdin pressing the button instead of rubbing the lamp. This is the modern way, replacing the ancient. "America's Electrical Week" has been instituted to increase sales and enthuse salesmen; it is the peak of the selling curve, the modern way of stimulating sales and brings prosperity beyond the fondest dreams.

The entire electrical industry will find this latest publication of the Society for Electrical Development, United Engineering Societies Building, New York City, instructive and an inspiring help especially during the campaign of "America's Electrical Week," but also throughout the coming year.

PERSONALS

Mr. B. D. Gray has been elected president of the Hess-Bright Manufacturing Company, Philadelphia, succeeding Mr. F. E. Bright, who remains as chairman of the board of directors.

Mr. W. J. Ballentine, formerly general superintendent of the Indianapolis works of the Link Belt Company, has been appointed manager of the Chain Belt Company, Milwaukee.

Prof. E. A. Fessenden, associate professor of mechanical engineering in the University of Missouri, has been elected head of the department of mechanical engineering of the Pennsylvania State College.

Mr. Ernest Alschuler, western manager of the Interstate Electric Novelty Company, Chicago office, has resigned to accept the appointment of sales manager of the American Carbon & Battery Company, East St. Louis, Mo.

Mr. J. S. Kennedy, of the Edison Electric Illuminating Company of Boston, has resigned to take charge of electrical sales of Landers, Frary & Clark, New Britain, Conn.

Mr. H. O. Swoboda, consulting engineer, Pittsburgh, Pa., has been appointed consulting engineer for the Pittsburgh & Butler Railway Company to take care of its interests in connection with its agreements with the West Penn Power Company, Pittsburgh, Pa.

Mr. Ford W. Harris, formerly engineer in charge of design of circuit breakers, switches and fuses for the Westinghouse Electric & Mfg. Company, was on October 5 admitted to practice law in the courts of California. Mr. Harris is specializing in patent law and trade-mark causes.

Mr. James G. Wray, chief engineer of the Central Group, Bell Telephone Companies, has resigned to become associated with Hagenah & Erickson, public utility engineers, First National Bank building, Chicago, and will specialize on appraisals, cost analyses and rate investigations.

Mr. L. Whiting, of the Detroit office of the Westinghouse Electric & Mfg. Company, has been appointed manager of the supply department for the Detroit district.

Mr. J. H. Bryan, industrial and power department of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has resigned to enter the business department of Simmons-Boardman Publishing Company, with headquarters in the Woolworth building, New York City.

The *Southern Public Utilities Magazine* for September reprints by permission the article by Mr. W. A. McKay, entitled "Development and Use of Mazda C Lamps," which appeared in the JOURNAL for June.

The *Telephone Engineer* for October reprints from the September issue of the JOURNAL the editorial by Mr. C. R. Dooley, entitled "The Constructive Analyst."

PERSONALS

Mr. W. C. Callaghan, superintendent of the Helena Light & Railway Company, at Helena, Mont., has resigned to become general manager of the J. G. White Management Corporation.

Mr. Arthur J. Hanzlik, mechanical engineer of the De Laval Steam Turbine Company, Trenton, N. J., has resigned to accept the position of consulting engineer of the Kerr Turbine Company, Wellsville, N. Y.

Mr. H. L. Lautenschlaeger has been appointed head of the material-following division of the purchasing department of the Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Mr. Lucien Barnes, export manager of the Westinghouse Electric & Mfg. Company, New York, has resigned to become purchasing agent of R. Martins & Co., 24 State street, New York City. This company does a large machinery export business with Russia and other European countries.

Mr. Reginald Arndt, sales engineer for the American Carbon & Battery Company, East St. Louis, Ill., has resigned to accept a position with the Central Union Telephone Company, Columbus, O. Mr. Arndt graduated from Ohio State University in 1913 and then became equipment-specification engineer in the general engineering department of the Southwestern Bell Telephone System, St. Louis, Mo.

Mr. R. H. Rigg, of the supply department of the Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa., has been transferred to the St. Louis district office of the company.

Mr. William M. Tomkins has been made Philadelphia representative of the Ward Leonard Electric Company, of Mount Vernon, N. Y.; address, 4813 Haverford avenue, Philadelphia, Pa. Mr. Tomkins' broad experience in the electrical field and his particular knowledge of dynamo-controlling devices puts the trade in a good position to receive expert information on these subjects.

Mr. W. R. McGovern has been appointed chief engineer of the Central Group, Bell Telephone Companies, to succeed Mr. James G. Wray. Mr. McGovern was formerly chief engineer of the Wisconsin Telephone Company and state engineer for the Chicago Telephone Company.

TRADE NOTES

The Spray Engineering Company, 93 Federal street, Boston, Mass., issued a new circular on their "Spraco" Paint Gun. This is a hand tool for use in applying all kinds of liquid coatings. The equipment consists of the paint gun proper connected by a flexible hose to a portable unit combining the material container, air dryer and strainer, pressure control attachment and pressure gauge. This equipment may be used for spraying the highest grade of varnishes and lacquers, as well as heavy asphaltum and structural paints.

John A. Roebling & Sons Company has issued its fourth number of a series of publications, entitled "Roebling's Wire Rope." The present one includes wire rope practice, wire rope efficiency, etc. Copies may be obtained by addressing the company at Trenton, N. J.

NEW BOOKS

"Applied Electricity for Practical Men" —Arthur J. Rowland. 375 pages, 327 illustrations. Published by McGraw-Hill Book Company, New York City. Price $2.00.

A number of books have been published on electrical subjects which do not demand of the reader any considerable acquaintanceship with mathematics and science. They have been mostly of two types:—One covering the whole range from electrostatics through current electricity to wireless telegraphy, with resulting superficiality. The other deals almost wholly with principles, but does not go to any considerable extent into the application of practical apparatus. The present work is designed for men who expect to make direct application of the principles needed in the classroom for their detailed work with commercial circuits and machinery. It does not take up problems of apparatus design, and power theory is avoided. The principles stated are such as are necessary to present the essential elements, but can be elaborated by the instructor, as it may seem desirable. The book is intended especially for those in trade and industrial schools and includes numerous problems for classroom work.

THE ELECTRIC JOURNAL

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Electricity in Metal Production

The unprecedented growth of manufacturing of all sorts during the past eighteen months has been accompanied by an equally great increase in metal production throughout the United States, which in turn has been attended with a corresponding increase in the use of electricity for operations incident to the mining, milling and smelting of the ores from which the metals are obtained. Never before have so many horse-power of electrical energy been used for the production of both base and rare metals.

The increased demand for metal has influenced the electrification of the mining industry in a number of ways. It has been used to increase the capacity of existing plants by speeding up production. It has been used in the development of new plants on account of its economy and convenience. It has permitted large savings in the operation of old plants, and has made possible the introduction of new processes of concentration, deposition and refining, which would not be operative with any other form of power. Furthermore, it has made possible the exploitation of large bodies of ore whose grade was so low that they could not have been worked but for the economies incident to the use of electric power. In addition, the widespread application of electricity to the industry has vastly increased the safety of many of its operations.

Not only has electrification been marked in recent years by tremendous growth, but hand in hand with this growth has come a decided refinement in the application of power to the various processes involved. More and more there is a tendency towards individual drive with the elimination of standby losses and the losses incident to mechanical power transmission. More and more automatic and semi-automatic control is displacing the old-fashioned hand-operated drum controller. Not only is the magnet switch control becoming popular for many applications for which in former years it was never considered, but it is notable that the use of liquid control for large alternating-current motors is also winning a prominent place in mining operations.

Apart from applications involving power supply for mechanical operations, electricity is finding new fields for itself in the metal-producing industry in the electrolytic process incident to the leaching of copper ores and the production of high-grade spelter. Where a few years ago large deposits of carbonate copper ores were considered unworkable because of their undesirability in the pyrometallurgical processes of the ordinary smelter, these same deposits are now becoming a decided factor in the copper production of the two American continents. Until very recently, indeed, all commercial zinc was produced by distillation, a process involving many difficulties, a comparatively impure product, and a very decided factor of loss due to certain peculiar tendencies of zinc vapor to solidify in undesirable forms. Today a very considerable quantity of the zinc produced in North America is deposited electrolytically from an acid solution obtained by leaching zinc concentrates, and the zinc so produced is purer and more homogeneous, and therefore more desirable in the trades, than that made in the old way.

Electrostatic processes are also developing a field of usefulness. The Huff process of zinc separation is becoming a commercial process of much promise. But the most prominent use of electrostatic processes is in connection with the various Cottrell installations, which are doing such good work in the smelters of the West. Here we have true conservation, for without this process much of the metal that is recovered in the Cottrell treaters is carried away as dust by the hot gases belching from the smelter stacks. This dust is not only lost as useful product, but may also constitute a definite menace to the vegetation of the surrounding country.

The progress of civilization is to a large extent bound up with progress in the use of the base metals, and this in turn is largely dependent upon the possibilities of metal production. Today there is no one factor so important in the metal production of the world as the application of electric power and electrical processes.

GIRARD B. ROSENBLATT

Railway Operating Data

The burdensome conditions under which the electric railways are forced to operate have created a strong demand for economy in operation and maintenance. New methods are developing under the spur of necessity so rapidly as to make obsolete most of the data heretofore published on the subject. It has therefore been decided to organize a clearing house for the interchange of information of this kind and to publish the best obtainable information under the heading "Railway Operating Data."

It is planned to devote one or more pages to this purpose in each issue, and as these pages are filled a fund of information of continually increasing value will be built up. Many of the sheets will automatically find their way into the particular department of the shop where the operation covered is performed.

The value of this new department can be promoted by JOURNAL readers in two ways:—If you have worked out a new method which is successfully solving a previously difficult problem, tell us about it. If you have no successful method yet perfected, ask for the best scheme now available. In this way we can work together to make this operating data hit the mark.

Converter Aisle of the Washoe Reduction Works

ANACONDA COPPER MINING COMPANY, ANACONDA, MONTANA

W. C. Capron
Assistant Chief Engineer

When the Washoe Reduction Works were built about 1900, small barrel converters were installed. This plant was increased in size later so that the final installation of this type of converter consisted of 13 stalls and 20 converters, capable of converting enough matte to produce a maximum of 18 000 000 pounds of copper per month. The Great Falls reduction department, at Great Falls, Montana, originally installed the upright Bessemer type of converter, of about the same capacity as those originally installed at the Washoe works. At both plants the converters were tipped by hydraulic power, no electric power being used in their operation.

FIG. 1—GENERAL VIEW OF CONVERTER AISLE AT THE WASHOE REDUCTION WORKS

The Great Falls plant decided about 1904 to increase the size of their converters, and settled on 12 feet in diameter as the size they would adopt. At the same time they changed the operating power from hydraulic to electric. The details of the drive were practically the same as that used at present.

About 1910 the management at Great Falls decided to increase the size of the converters, and a size 20 feet in diameter was adopted. This mammoth converter, taking 75 tons of matte at a charge, proved so successful that in 1912 one was installed at Anaconda. This also was entirely successful, and it was decided to remodel the entire converter plant at Anaconda, installing seven 20 foot Bessemer-type converters in place of the 13 small barrel-type converters. The new converters are so heavy they are never lifted out of their stalls for repairs. The last large converter was blown in early this year and the plant is now capable of converting enough matte to produce 1 000 000 pounds of copper per day, using six converters and keeping the seventh for a spare.

In Fig. 1 is shown a general view of the converter aisle. Fig. 2 shows a front view of the converter tilted forward and pouring copper into a ladle. This ladle is then picked up by a traveling electric crane and carried to one of the casting furnaces, where it is set in a chair which is tilted by an electric tilting device, and the copper poured into the furnace. At the top of the picture can be seen the smoke hood into which the gases discharge when the converter is upright and blowing;

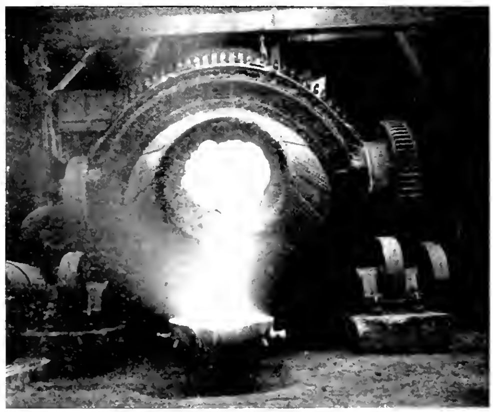

FIG. 2—FRONT VIEW OF A 75 TON CONVERTER IN THE TILTING POSITION

The converter is 20 ft. in outside diameter; 15 ft. 6 in. inside diameter; 17 ft. 8 in. high; and has an 8 ft. opening. The outer ends of the tuyeres appear at the top in this view.

also the spout through which the matte is charged into the converter.

Riveted to the converter shell are two cast-steel trunnions, nine feet in diameter, one of which (the right one in Fig. 2) is flanged, and each of which ride on two six-foot rollers. The flanged trunnion carries the main gear, which is of cast steel approximately 12 feet in diameter and meshes with a cast steel pinion 30 inches in diameter, both gear and pinion having 15 inch faces. The pinion is on the same shaft with a cast-steel worm wheel about five feet seven inches in diameter, which is driven by a bronze worm and, in turn, is connected to the motor through another set of gears. All the mechanism, from the cast-steel pinion to and including the motor and brake, is housed in to prevent injury from splashing

metal from the converter and cold metal falling off the converter. The approximate weight of the converter when blowing is:—

Lining	112.5 tons
All metal parts	113.5 tons
Charge	75 tons
Total	301 tons

At the left of Fig. 2 can be seen a large pipe connecting with the center of the trunnion. This is where the air enters. The trunnion on this side is hollow and the air goes through it and into the wind box, which is seen around the upper half of the converter in the position shown. The air enters the converter through the tuyeres, which are connected to and just below the wind box.

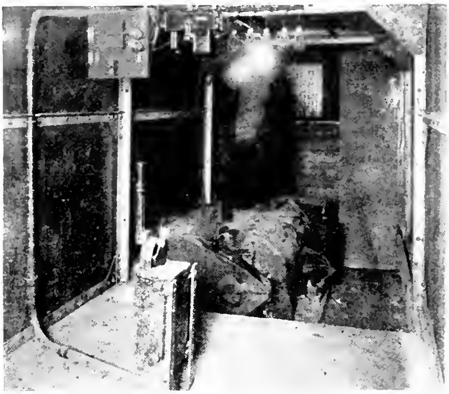

FIG. 3—ONE HUNDRED HORSE-POWER, DIRECT-CURRENT MILL MOTOR FOR TILTING THE CONVERTERS

The metallurgical operation of the converter is as follows:—A mixture of matte from the reverberatory furnaces and from the blast furnaces weighing from 65 to 80 tons is brought in ladle cars to the converter plant on the upper level or charging floor and is poured into a receiving bowl, from which it runs through an open launder directly into the mouth of the converter. The blast matte contains about 46 percent copper, 25.5 percent iron and 23.5 percent sulphur. The reverberatory matte contains about 39 percent copper, 29 percent iron and 24.5 percent sulphur. The resulting mixture contains about 43 percent copper.

Before the matte is put in a boat of floor cleanings and a boat of ore is charged into the empty converter. After the matte is charged the first period of the blow commences. Air is turned on and enters the converter through 31 tuyere pipes 1.75 inches in diameter, the pressure varying from 9 to 19 pounds and averaging about 14.5 pounds. About 240 000 cu. ft. of free air is used per ton of copper produced. The six converters which are operated consume about 17 000 000 cu. ft. per day. The air which passes through the molten matte burns the iron and part of the sulphur. The sulphur passes off as a gas while the iron is oxidized and enters into a combination with the silica in the ore to form a slag, this combination containing 22 percent silica and 69 percent iron oxide. In burning the iron and sulphur, the temperature of the charge increases from 1800 to 2200 degrees F. More ore is added as the temperature reaches the danger point until there is enough to flux all the iron. The first period is then complete, and has taken about five hours and fifteen minutes. There are present at this point two materials; the copper, combined with one-fourth its weight of sulphur, in the bottom of the converter,—on top of this the slag. The converter is tilted and the slag allowed to run off into the cast-steel ladles. This slag is cast and, as it contains from four to five percent copper, is returned to the blast furnace for retreatment.

When the slag is all poured off, a boat or two of cold copper or white metal (copper sulphide) is added to reduce the temperature; the converter is then turned to an upright position and the air blast turned on again. This period takes about three hours and ends when all the sulphur has been oxidized and only metallic copper is left. The copper is then poured into ladles and taken to small reverberatory furnaces, where it undergoes a preliminary refining so it will cast into smooth anodes for electrolytic refining. Each converter treats per day from 200 to 240 tons of matte, and produces about 75 to 80 tons of copper.

The converters are tilted by 100 hp, 500 volt, direct-current motors, equipped with magnetic and post brakes. The motors are located in the rear of a corrugated iron control house at the side of the converters, Fig. 3. The master controller is located in the front of the control house. On the ceiling a set of pilot lamps indicates when the power is on and off. There is also a small oil switch and double-pole, double-throw knife switch which controls the two horse-power motor that operates the air valves.

FIG. 4—AUTOMATIC CONTROL PANELS FOR OPERATING THE TILTING MOTORS

In the rear of the converters is another corrugated iron house, which contains two direct-current automatic contactor panels for controlling the 100 hp motors on two converters, as shown in Fig. 4. The master controller has five points in the forward and five points in the reverse direction. This operates the contactor panel, the first notch closing either the two outside or the two inside contactors at the top of the panel, according

to the direction desired. The remaining four notches, each in turn, close the contactors at the bottom of the panel from left to right, thus cutting out the resistance and speeding up the motor. Each contactor has an interlock, shown just below it, which automatically regulates the operation of the succeeding contactors.

In the center of the panel is a double-pole, single-throw knife switch, which is the main switch for the unit. Directly above this is a small contactor or overload relay which, when operating on an overload, throws out all the contactors in service. At the left of the main switch is a smaller double-pole, double-throw knife switch with fuses, which is the main switch for the control of the large contactors, thus giving current to the small contactors at the lower right-hand corner of the contactor panel.

When the master control handle is in the neutral position the motor brake comes into service by means of springs clamping the brake shoes to the pulley, and when the controller is on a notch in either direction the post magnet is energized and releases the brake.

A hand-operating device is being installed on one converter for trial. If the electric current goes off when a converter is blowing it is liable to cause serious damage for, unless there are enough steam-driven blowers on the blast line to keep up the pressure, the tuyeres fill, and if the blast goes off entirely for any length of time the converter is in danger of freezing. A hand-operating device will allow tipping the converter immediately to throw the tuyeres out of the bath, and if the blast is off long enough to be serious the metal could be poured, although the process would be quite slow.

Electric Power in Gold Dredging

T. D. Prier
Electrical Engineer,
Conrey Placer Mining Company

Dredge mining for placer gold has been one of the most attractive fields for investment of capital in recent years. The number of gold dredges in successful operation in the United States has greatly increased during the past decade, and especially in the last six years. The early New Zealand spoon dredges were operated by hand power with some success in 1865. Later in 1870 a modification of the spoon operated by steam power, a primitive steam shovel dredge, was worked in New Zealand. Steam shovel dredging was attempted in California as early as 1888, and with some success in later years. The elevator gold dredge with endless bucket chain was put into operation in New Zealand in 1882 and operated by water current wheels. In 1897 R. H. Postlewaite introduced the gold dredging practice of New Zealand into California. The first successful bucket-lift dredge in the United States was that erected on Grasshopper Creek, Beaverhead County, Montana, near the town of Bannock, where the first capital of the State of Montana was situated in 1864-65.

In the gold production from dredging operations in the United States, Montana ranks second, next to California, with a yield to the end of 1914 estimated at about \$6 800 000.

GOLD DREDGING IN ALDER GULCH, MONTANA

Alder Gulch empties into the Ruby River, a tributary of the Jefferson, a branch of the Missouri, and is in Madison County, Montana. Gold was found in Alder Gulch in 1862 in such quantity that its richness is renowned in the placer mining history of this country. It has been estimated that in early days gold to the value of forty to ninety million dollars was taken from the sixteen miles worked.

After the cream of the gold had been skimmed by pan, rocker, long-tom and short sluices, the gulch was worked over again, and in some places for a third time, by ground sluicing and other placer mining methods; and finally endless chain bucket-lift dredges are being employed to obtain the last remnants of the gold.

CONREY PLACER MINING COMPANY

The headquarters of the Conrey Placer Mining Company are at Ruby, about a mile and a half from Alder, Montana, a branch terminus of the Northern Pacific, and about eighty miles by rail from Butte. The Conrey company started its first dredging operations in 1899, and since that date has worked, in the Alder Gulch district, some 37 000 000 cubic yards of gravel, with an average yield of about 16 cents per cubic yard.

This company has had in operation seven dredges, three of which have been abandoned and four are now in operation. The three abandoned were the Maggie Gibson and dredges 1 and 2, which were single bucket-lift sluice dredges, driven by steam. Of the present dredges at work, No. 3 is a single bucket-lift sluice dredge, driven by electricity, and the other three are electrically-driven, bucket-lift stacker dredges of the type used in California.

The steam dredges worked some 6 000 000 cubic yards of the richest gravel below the mouth of Alder Gulch, averaging about 22 cents a cubic yard. Even though the gravel worked showed such exceptional richness, the operations yielded little if any profit to the owners when the loss of capital by the abandonment of the dredges was taken into consideration, as the cost of dredges 1 and 2 amounted to about \$225 000.

ELECTRIC GOLD DREDGES

The advent of the electric motor may be said to have marked the beginning of a new epoch in gold dredging. Although the induction motor has been available for industrial use for less than twenty-four years, a consid-

erable part of the gold mined in the United States is now recovered by motor-driven dredges. With the rapid extension of the western hydroelectric transmission systems, cheap power is now available in most placer mining districts. Not only has cheaper power made the electrical dredge superior to the steam dredges, but other advantages are:—

1—Saving in capital and first costs by the purchase of power.
2—Efficiency.
3—High percentage in operating time.
4—Flexibility.
5—Ease of extensions.
6—Better and more sanitary conditions for dredge crew.
7—Saving in labor and repair costs.
8—Larger sizes of gold dredges would hardly be possible with steam equipment.

Dredge motors are mostly of the alternating-current class, the variable-speed type being required for the operating of the bucket line, as well as for the winches, which control lines to move the dredge about in its pond. The centrifugal pumps, screen and stacker motors are of the constant-speed type.

The initial problem in the motor-driven dredge involved peak loads and excessive shocks received by the motor driving the bucket chain, due to boulders and cemented gravel. The adoption of a slipping friction gear on the first intermediate shaft and meshing with the motor pinion, together with an automatic overload, time limit relay, circuit breaker installed in the motor primary, has successfully solved all such troubles. The control of the digging motor in the larger gold dredges has been greatly improved by the introduction of a water rheostat.

SOURCE OF POWER

Power for all electric dredges at Ruby, Montana, is obtained from the Madison River power plant, twenty-six miles distant, and is transmitted to the Conrey substation at 46 200 volts, where it is stepped down to 2200 volts and sent direct to the dredges over independent power lines.

Dredges 1, 2 and 3 have 2200 and 440 volt motors, and transformers are placed on these dredges for further reduction of voltage of part of the power. Dredge 4 uses 2200 volts throughout, and only one transformer for the lights is required.

At the substation there are three banks of transformers capable of supplying 2815 horse-power of motors, with a maximum reduction of 80 000 to 2200 volts. Two banks are in constant use, the third being held in reserve. Over $50 000 has been spent in connection with this station and the different power lines to the various dredges and to the machine shop.

The inefficiency of the steam dredge was so impressed on the Conrey directors that, prior to the favorable arrangement made with the Madison River Power Company, decision was reached to generate electric power by steam from a central station and to distribute it to the dredges, for it was often a serious matter to coal the dredges in cold and stormy weather and in comparatively inaccessible positions. Considerable trouble was also experienced with the boilers, owing to the muddy water from the ponds.

Table I depicts the struggle to increase yardage and to lower working costs. Working costs commenced with 16.5 cents with steam dredges and were reduced to 5.26 cents per cubic yard in 1914. Over 31 000 000 cubic yards have been dug by the Conrey electrical dredges with an operating cost of 6.96 cents per cubic yard.

TABLE I—GENERAL STATISTICS CONCERNING DREDGES AT RUBY, MONTANA

Item	Steam Dredges			Electric Dredges			
	Maggie Gibson	Conrey No. 1	Conrey No. 2	Conrey No. 1	Conrey No. 2	Conrey No. 3	Conrey No. 4
Date built	1896	1899	1901	1908	1908	1906	1911
Type	Double lift Sluice	Single lift Sluice	Single lift Sluice	Single lift Table, Stacker	Single lift Table, Stacker	Single lift Sluice box	Single lift Table, Stacker
Average monthly yardage worked, cu. yds.	27 000	41 360	52 520	96 270	62 709	82 415	300 000
Drive	Sprocket chain	Sprocket chain	Sprocket chain	Belt	Belt	Gear	Gear
Capacity of buckets, cu. ft.	5	5 to 7½	10	7½	7½	9½	16 to 18
Buckets dumped per min.	7	5 to 11	5 to 11	16	15	15	18 to 22
Gallons water per min.	4 000	6 500	8 100	6 700	6 700	12 500	12 000
Total gold saving area, sq. ft.	320	656	692	1231	1231	1264	3000
Horse-Power of:—							
Bucket chain	45	60	73	100	100	150	550
Trommel	5	6	8	30	30	10	100
Pumps	40	79	147	160	160	175	285
Winches	10	12	4	20	20	115	250
Miscellaneous	None	19	16	70	70	10	50
Total horse-power	100	176	248	380	380	460	1235
Cost per yard	16½	16½	16½	6.96	6.96	6.96	6.96
Power cost per yard	3.27	3.27	3.27	1.32	1.32	1.32	1.32
Percent running time	35	35	35	70	70	70	70
Number of men	13	15	15	8	8	10	10
Cost of dredge	$225 000	$225 000	$225 000	$108 000	$128 000	$198 000	$296 000

ELECTRICAL DREDGE NO. 3

The No. 3 electric dredge is known as a single-lift sluice dredge. The hull is 130 by 48 feet by 7 feet 11 inches, and contains 400 000 feet of lumber. The total motor rating is 460 horse-power. This dredge started in September, 1906, with 43 open-connected buckets.

The bucket chain is driven by a special 150 horse-power, three-phase, 60 cycle, 2000 volt, 360 r.p.m., 20 pole, wound-secondary motor, capable of carrying 100 percent overload. It is interesting to note that this was the first gold dredge motor in the world to be direct geared to a bucket chain through a slipping friction.

The controller is of the 17 point reversing drum type. This enormous grid installation gave splendid control to the bucket chain speed, but more or less trouble has been experienced due to heating of the grids, as the motor is usually operated on the ninth to eleventh points of the controller; also due to grids breaking on account of vibration of the dredge.

ELECTRIC STACKER DREDGES 1 AND 2

The electric stacker dredges 1 and 2 were constructed on the lines of California practice of 7.5 cubic foot enclosed-connected bucket chains, with tailing stacker. They were started in 1908. The power is three-phase, 60 cycles, at 2200 volts. The dredge is connected with the pole line by means of a heavy insulated armored submarine cable, which enters at the stern of the dredge. At the point of entry there is an oil switch

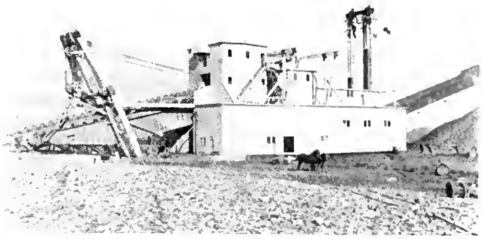

FIG. 1—ELECTRICALLY-DRIVEN, BUCKET-LIFT, STACKER DREDGE

so that the power can be turned off from the dredges at that point. There is another oil switch which controls the lighting circuit. This arrangement allows the motors to be cut off without affecting the lights. From the oil switch at the stern the main lines run to the switchboard in the pilot house, and from there the power is distributed to the various motors and lights.

Bucket-line motors for digging gold-bearing gravel vary in size from 75 to 550 hp. and are generally of special design to withstand heavy strains and peak loads. The control must be flexible to obtain best results.

When a dredging operation is commenced on a new cut the load is usually light at first and the buckets may be operated at maximum speed. As the depth increases and the gravel becomes more compact the load increases, the buckets require more time to fill, and the speed must be reduced as required.

On electrical dredges 1 and 2 the digging motor is 100 horse-power, 60 cycle, three-phase, 2200 volts, 580 r.p.m., variable speed, with external secondary resistance, operated by a nine-point reversing controller in the pilot house. These motors are connected to the tumbler driving the bucket chain by a system of two belts and two sets of gears, giving four reductions in speed.

The larger motors, 50 hp and over, operate directly at 2200 volts without intervention of transformers. The smaller motors operate at 440 volts and are supplied through a bank of three step-down transformers, 2200

FIG. 2—CONREY DREDGE NO. 4
The 550 hp, three-phase motor which is required to operate the buckets makes this the most powerful gold dredge afloat.

to 440 volts. These transformers are of the oil-cooled, outdoor type and are installed on the outside of the dredge near the bow on the first deck.

ELECTRIC DREDGE NO. 4

The No. 4 dredge was designed to work economically large areas of ground with small gold contents to a depth of 55 feet below water level. The record month's performance (May, 1915) of digging 411 000 cubic yards with 82 percent running time, with a depth of 54 feet and operating cost of 2.66 cents per cubic yard, justifies a more detailed description of the digging apparatus.

FIG. 3—OPERATING UNDER DIFFICULTIES
The large rock, which was brought up by the buckets, indicates the severity of the service which must be met by this equipment.

The hull is 150 feet long, 68 feet wide and 13 feet deep. The machinery for the dredge weighs 2 280 000 pounds and 660 000 feet of lumber were used in the hull, making a total weight of about 2000 tons for the com-

plete dredge. The buckets each hold 17 cubic feet of gravel.

When No. 4 began work in 1911 the digging motor, though as powerful as had been used before, was inadequate for its work, and it was replaced by a specially designed motor geared directly to the bucket chain. This motor is the largest in use in gold-dredging practice and is 550 hp, three-phase, 60 cycles, 14 pole, 2200 volts, wound-secondary motor, built on an 18 inch wide frame.

FIG. 4—BUCKETS USED ON ELECTRIC DREDGE
The lips which are riveted on are of manganese steel.

Under normal rated conditions of voltage and frequency the motor will operate at its full rated torque at any speed from full load to 75 percent full-load speed continuously with a rise in temperature above the surrounding room temperature not to exceed 40 degrees C., and under the same conditions it will operate under load corresponding to 125 percent of its rated full-load torque continuously at any speed from full load to 75 percent full-load speed with a rise in temperature above surrounding room temperature not to exceed 55 degrees C. Its percent efficiency is approximately 90 at one-half load; 91.5 at three-quarters load; 92 at full load. Its percent power-factor is 77 at one-half load; 85 at three-quarters load; 88 at full-load. The starting torque is the same as the pull-out torque, and is 2.5 times the full-load torque. The electrical installation is similar to that of Nos. 1 and 2 on a larger scale, with the exception that all motors are on a 2200 volt circuit.

The control of this motor is worthy of more detailed description. The resistance in the rotor circuit is not intended as an initial starting device only, but is used as a speed regulator for the bucket chain as well, and is carrying current most of the time the motor is under load. Cast grids were giving trouble by overheating and breaking, and the weight was excessive for a motor of this size. The water rheostat control was therefore installed with some slight modifications. Six electrically-operated magnetic contactors installed in the pilot house, three forward and three reverse, for the primary circuit to the motor are operated by a master controller at 220 volts. The lever to the master controller also raises and lowers the weir in the water rheostat, thus varying the resistance in the rotor circuit at the same time the primary is closed. To go from forward to reverse the weir must pass through its lowest point, completely emptying the electrode tank and placing maximum resistance in circuit. This controller and rheostat are capable of controlling the speed of the motor continuously at any speed from full load to 75 percent full-load speed when operating at any torque from full load to 125 percent full-load rated torque. These liquid rheostats are capable of very high resistance and extreme smoothness in rate of change. Pure water is seldom used, some salt being added to the water to increase its conductivity.

The radiation capacity of a liquid rheostat as applied to a dredge was a severe problem. Prior to the Conrey installation the method of cooling the liquid was by immersing coils of pipe in the rheostat tank and circulating pond water through them. Clogging with mud from the water made this method a failure. As applied on dredge No. 4, the coils of pipe are fastened to the hull of the dredge in the pond and the electrolyte is pumped through them and back to rheostat. This method of control has been in operation for several years and the speed of the digging chain has ranged from 22 buckets per minute in top loam and loose gravel to 17 buckets per minute at a depth of 50 feet below water level in compact digging.

GENERAL

The extent of the development of dredging in Montana in 20 years extends from the early steam dredges with their total weight of 450 tons and 100 hp each to Conrey electric dredge No. 4, weighing 2000 tons and having 1235 horse-power.

FIG. 5—ICE CONDITIONS IN THE WINTER
The hull is entirely out of sight under the ice.

The superiority of the modern electric locomotives over the early ox teams and steam trains in costs, comforts and advancement of civilization is analogous to the growth of the hand, water wheel and steam dredge into the giant electrically-operated machine.

Individual Motor Drive for Flotation Machines

E. SHORES
Metallurgical Engineer,
Stimpson Equipment Company

THE greatest recent progress in the concentration of low-grade ores has been accomplished by the introduction of what is termed "flotation" into metal milling practice. Just what makes a metalliferous ore of certain character "float" is a much-mooted question, but the fact remains that sulphides of many of the baser metals, and for that matter some carbonates and several native metals will adhere to the surface of soapy or oily bubbles, while non-metalliferous substances, such as sand, powdered rock and the other mineral substances in whose presence the metals are found in nature, will not do so. Accordingly, if ore-bearing rock is finely pulverized and then mixed with a solution of water carrying some saponaceous oil and the mixture stirred and agitated so that bubbles are produced, these bubbles will naturally rise to the surface and carry with them, clinging to their film, that part of the powdered rock which is metalliferous. This is termed floating the ore and, when properly applied, will recover even from comparatively low-grade ore a much greater proportion of the metallic matter than was ever possible with the old systems of gravity concentration, which depends for its operation on the settling out of the metallic matter from a moving mass of water due to its specific gravity being greater than that of the rock with which it was associated.

The production of the bubbles as a froth or foam in the presence of crushed ore is termed agitation and may be accomplished in a number of ways, all of which are variations or combinations of two fundamental methods, viz., of either bubbling air through the solution or beating up the solution in the presence of air. In any event it must be a carefully adjusted process; and dealing as it does with a raw material in which the values per ton (and therefore the profits per ton) are low and subject to disappearance if the process is not carefully applied, the operation of a flotation plant necessarily depends upon the summation of many minor economies. In this way the production of metals on a profitable scale from low-grade ores takes on all of the aspects of a manufacturing enterprise. In fact, it is manufacturing, just as much as is fabricating steel from iron ore, or weaving cloth from cotton, or making paper from wood. And here, as in other manufacturing processes, direct-connected individual motor drive has won well-merited recognition for itself.

THE advantages of individual motor drive in first-class machine shops have long been recognized. The savings in space is quite important. The dangers always connected with line shafting and belts are eliminated. The operator has more complete control over his machine, and a wider variation in speed may be obtained if necessary. The machine may be shut down without the necessity of shifting to a noisy loose pulley or hanging up the belt, or without affecting other machines.

All the advantages derived in the shop by the use of individual motor drive may be had with equal facility in the concentrating mill. Individual drive is being used with success on concentrating tables and, recognizing all the advantages to be obtained from this method of applying power, it has been adopted for the drive of the Janney flotation machine. The designers of the Janney cell, men of wide experience in the operation of the large concentrators, considered all methods of drive very seriously before adopting individual motors. At first glance it seemed that the first cost would be excessive, but upon closer analysis it was found that the initial outlay for group drive and for individual drive was just about the same. In designing a mill for dis-

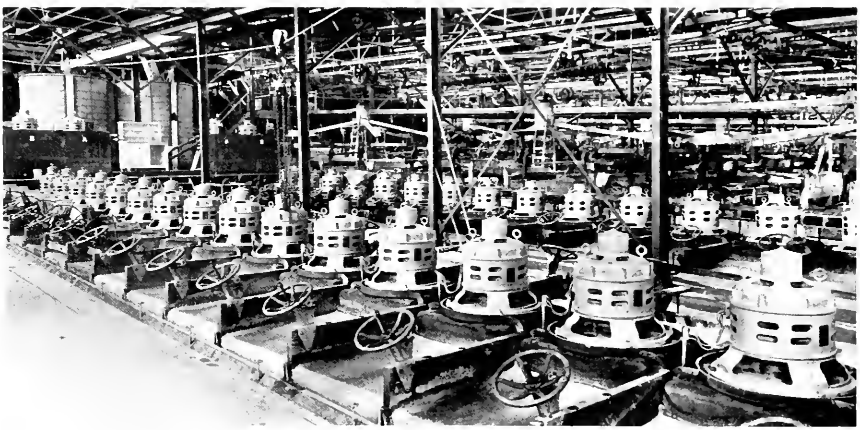

FIG. 1—A TYPICAL INSTALLATION OF JANNEY CELLS WITH INDIVIDUAL MOTOR DRIVE

tribution of power by means of line shafts and belts the upper steel structure has to be made heavy enough to carry this load. Extra trusses and columns to take the shafting strains must be provided. There is considerable friction loss with any arrangement of shafting, and this is greater than it should be as a rule, due to the fact that a shaft gets out of alignment from the settling of the building or other causes and is seldom trued up again. To readjust it would take time, which is always at a premium, and hence, as long as the shafting will run without appreciable difficulty, it is usually left alone.

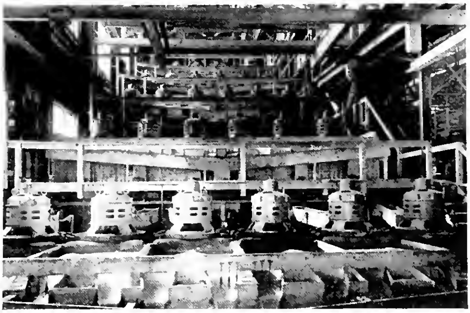

FIG. 2—BATTERY OF FLOTATION MACHINES
Driven by 10 hp motors.

The percentage of lost time per machine is decidedly in favor of the individual drive. The motors are such that they do not give any trouble and will run continuously for months. On the other hand, the time lost in a mill due to belt trouble is always considerable; especially with the smaller belts. They must be kept at just the proper tension or else they give trouble; trouble means the adjustment of that belt, and of course a delay. In no method of concentration is the necessity of steady, continuous operation so essential as with flotation. A shut down in a flotation plant is a serious matter, since it takes considerable time to get everything into proper adjustment after again starting up. During the time this adjusting is being done the results are off and a direct loss is the result. The only time a Janney machine needs to be shut down is when the power is cut off or the operator shuts the machine down for replacement of parts worn out. The machine may operate continuously for from two to three months without need of stopping. When this is necessary the changes in most cases may be made in twenty minutes and the machine is ready for another period of continuous operation. And only one machine at a time need be shut down.

The motor drive on each flotation cell makes it possible for any number of machines to be placed very closely together, thereby giving great economy in the floor space required. It also leaves all the space above the machines open for crane service.

From the flotation operator's standpoint the individual motor drive is ideal. It eliminates one of his principal troubles—the mechanical operation of the machine. His whole time may be given to other matters. All this tends to produce the best metallurgical results. To the individual motor drive must be given much credit for the success and popularity attained by the Janney flotation machine.

The motor used with these machines was developed especially for this service after an exhaustive study of the application. The types of fumes that will likely be met with in the handling of various classes of ore were investigated and an insulation was designed to withstand corrosive action. Power requirements and torques involved were studied and a motor to meet the particular requirements with maximum efficiency was evolved. The mechanical requirements of the service received particularly careful consideration. It being manifestly impossible to support successfully the vertical shaft carrying the agitator paddles by a step bearing inside the flotation cell, it became necessary to suspend this shaft from the shaft of the motor itself. Accordingly, a step bearing was provided at the top of the motor, with sufficient capacity to sustain the weight of the revolving part of the motor, the weight of the motor shaft, the weight of the agitator paddles together with their shaft and coupling. This is a ball bearing which is continually flooded with oil, and so successful has been the design of the lubricating system that in several years of operation no trouble has been experienced due to failure of lubrication on the step bearing.

As a slight unbalancing of the paddles at the rotative speed of approximately 600 r.p.m. used in these cells would cause excessive vibration due to the long length of shaft between the step bearing and the paddles themselves, a heavy guide bearing is provided below the motor and above the paddles, this bearing being integral with the lower end bell of the motor.

The whole motor construction and drive was devised under the guidance of experienced operators of the largest concentrating mills in the country, so as to reduce maintenance, insure continuity of service, and permit ease of lubrication, inspection and assembling. The success that has attended the application is a testimonial of what careful study of commercial operating conditions can insure in the way of satisfactory performance.

FIG. 3—INDIVIDUAL AGITATOR MOTORS
Used with Janney cells in the ore flotation system of separating base metals from low-grade ores and tailings. The emulsifier or mixer cell is shown in the upper left-hand corner.

Electricity Applied to Metal Mining

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Superintendent of Mountain Division,
Arkansas Railway, Light & Power Company

A CONSIDERABLE advance in the application of electricity for mining purposes has been made in the Cripple Creek gold mining district and in the Canon City coal fields of Colorado. Service to these districts was begun in 1898. For a number of years there was considerable competition in the supply of electric service. There were three central stations competing for business, the principal revenue being derived from the lighting service, and in the early boom days of the Cripple Creek district a large amount of lighting was used day and night at a rate of approximately 20 cents per kilowatt-hour.

At first the operating companies were able to secure only auxiliary power applications, such as small hoists, conveyors, sawmills and underground applications where it was difficult and expensive to maintain steam and compressed air pipe lines. Rates were comparatively high. A great deal of difficulty was experienced by the central stations in maintaining service during lightning storms, and continuity of service during the summer season could not be guaranteed. It was not unusual for an operating company to work up a fairly good day power load during the fall and winter months, and by the end of August find a considerable portion of its customers had cut out electric service and installed steam equipment. As high as 25 percent of the distributing transformers would be more or less damaged in one season, and considerable trouble was experienced on the 500 volt, three-phase distribution circuits. It was often necessary to disconnect customers' meters during the lightning period and estimate customers' bills because none of the earlier meters could be relied upon during the lightning season; also 440 volt motors suffered severely from lightning disturbances.

So far as known, the first high-tension commercial aluminum cell arrester was tried out in the Cripple Creek district, and the original set was, until a few years ago, still in operation. At the time this arrester was installed for experimental purposes the local company was already operating a few crude home-made experimental aluminum arresters on the 500 volt customers' service with excellent results.

The business suffered from too keen competition, there being at one time four competing central stations in the gold mining district. Occasionally one company, by reason of accident or lack of load, would sell or purchase service from a competitor. Certain of the larger customers would frequently be changed from one company to another, and the smaller customers were changed from one to the other very frequently. At one time one of the companies operating a hydroelectric plant without steam reserve was obliged, on account of the shutting off of the water supply by cold weather, to connect its load to the lines of its competitor just before dark as the lighting load was coming on. Its manager succeeded in entering into a contract with the manager of the competing company at a reasonable rate before his employees could advise him of the source of the extra load. The hydroelectric company then succeeded in getting a supply of water from a reservoir belonging to one of the municipalities which, on account of the newness of the reservoir, was unfit for domestic use. The state militia, being then in control of the mining district on account of a serious labor strike, was obliged, under the plea of military necessity, to open the gates of a reservoir belonging to a distant municipality and secure therefrom an adequate supply of pure water from the western slope of Pike's Peak.

FIG. 1—SOUTHERN PORTION OF THE CRIPPLE CREEK MINING DISTRICT, SOME

The advent of the aluminum cell arrester enabled the operating companies to give reliable service and gradually develop the power load of the mines. Air compressors were the first large loads taken on, and later ore mills running 24 hours per day were served and also other loads requiring continuous service.

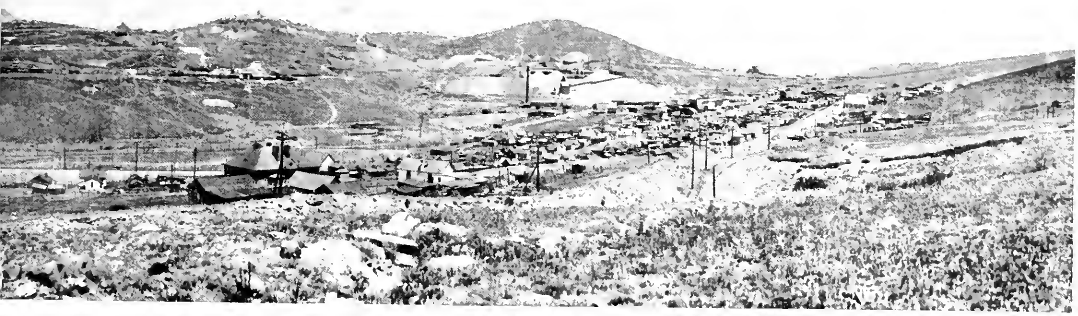
In 1911 the properties at Pueblo, Canon City, Cripple Creek, La Junta, Rocky Ford and surrounding territory were taken over by the Arkansas Valley Railway Light & Power Company, under the management and control of H. M. Byllesby & Co., of Chicago. The generating plants were enlarged and the service was in general greatly improved by this consolidation. Three plants are now operating in parallel, one in Pueblo, one in Canon City and a hydroelectric station near Victor, operating under a head of 1150 feet. The system supplies service to cities, coal mines, metal mines, cement mills, ore mills, oil wells, various city factories, irrigation pumping and agricultural districts. The resultant load of the combined district has a relatively high load factor.

The application of electric power to mining has been quite rapid in the last few years. At the present time there are approximately 16 000 hp connected in the Cripple Creek metal-mining and Canon City coal-mining districts. Considerable additional power is contracted for. All the coal mines in the Canon City field purchase electric service; although not all of them have entirely displaced some of the older steam equipments. The same is true of the metal mines. It is difficult at times to show sufficient saving to warrant the customer in discarding expensive steam equipment where the load factor is not high. Especially is this true if the mining company has no extensive ore reserves, or where underground development has not been carried out systematically ahead of production. Each case is an individual problem, requiring special treatment.

The cyanide process of extracting gold from ores has permitted the treatment of very low grades of ore directly at the mines, saving the heavy transportation expenses to valley treatment plants. Recently the flotation process has been successfully applied to the local treatment of gold ores, which opens up a vast supply of low-grade ores that can be profitably treated.

All transmission circuits supplying the Cripple Creek mining district are operated at 30 cycles, 22 000 volts, and distribution to the larger customers is made at the same voltage. Smaller scattered customers are supplied at 6600 volts. Customers usually receive service at about 460 volts. Four transmission circuits supply this company, terminating in a switching station equipped with reverse power relays. These relays have not been entirely satisfactory and are being changed to the definite time limit type of relay. La Bella plant, one of the large steam stations in this district, has been remodeled into a synchronous condenser station. The three 600 k.v.a. generators were disconnected from the cross-compound engines and are floated on the line as condensers. Street railway motors are geared to the crank discs for the purpose of bringing the generators up to synchronous speed. Two small condensers are operating at two different substations, and also two large synchronous motors direct connected to air compressors are operating over-excited. The power-factor of the system is maintained at any point desired.

Most of the mines of the Cripple Creek gold mining district are drained by the Roosevelt Tunnel, which is being driven and which now has a length of 22 000 feet and a depth of 2200 feet. This tunnel is driven by a company whose stock has been subscribed by the various mining companies. The cost of the tunnel is approximately $750 000. The geologic features of this mining district are unique. The entire district is composed of an extinct volcano, the top of which has been eroded, leaving a crater about six miles in diameter and of irregular shape. The walls of this crater are granite and the depth of the crater is unknown. This tunnel taps the crater at a depth of 2200 feet and drains the entire volcanic area. One large mining property is cut off from this drainage by a dike of dense material and the drainage tunnel has not yet penetrated this dike. This property is pumping from the 2000 foot level to the surface, using three triplex horizontal pumps, each driven by 175/85.5 hp motors, running at 600/300 r.p.m., connected through flexible couplings to large herringbone gears. A centrifugal pump in the bottom of the shaft raises the water to the plunger pumps. The over-



OF THE PRINCIPAL MINES AND THE CITIES OF VICTOR AND GOLDFIELD

all efficiency of these plunger pumps was carefully measured and was found to be 83 percent from the switchboard on the surface to the water discharged at the surface. The guaranteed efficiency of the motors and pumps combined was 76.5 percent.

Mining companies are encountering rich ore bodies at the tunnel level, which are presumed to extend at least a considerable depth below. The Portland Gold Mining Company, one of the oldest and richest of the mines, has remodeled its 500 ton mill and will enlarge it to a capacity of 1250 tons daily capacity, which will require about 3700 hp in motors.

No extremely large hoists have been electrified in this territory, the largest electric hoist in use being about 200 horse-power. The hoisting duty is severe: the shafts are deep, and in order to move the amount of ore required from the mine high speeds are required. A considerable number of smaller hoists, especially in the

FIG. 2—TRANSMISSION LINE TO CRIPPLE CREEK DISTRICT
Showing Portland and Independence mines in the background.

coal-mining district, are being served. One flywheel set hoisting equipment is being operated in the Coal Creek shaft of the Colorado Fuel & Iron Company. The Arkansas Valley Railway, Light & Power Company has constructed an additional line from Canon City to Victor. The Canon City plant is being increased by the addition of a 7500 kw steam turbine plant, complete with new boilers and auxiliaries, and will shortly be in a position to handle more severe loads.

A recent application has been made of underground storage battery locomotives in the Portland Gold Mine, which successfully replaces a considerable number of manual trammers, costing three dollars each per day. All drilling is done by compressed air drills, hand drilling being practically a thing of the past. Air compressors are all driven by constant-speed motors, either induction motors or, where direct connected, by synchronous motors. Governing is done by unloaders of vari-

FIG. 3—TYPE OF STRUCTURE USED WITH SPANS OF 1600 TO 2000 FEET
These spans are necessary to supply the Cripple Creek mines, where the rough country will permit material to be delivered only on the high ridges.

ous types operated by air pressure. About 90 to 100 pounds air pressure is maintained.

The annual output from the Cripple Creek district is approximately 1 000 000 tons of ore, with a gross value

FIG. 4—MOTOR-GENERATOR, FLYWHEEL HOISTING SET OF THE COLORADO FUEL & IRON COMPANY AT COAL CREEK
The stove whose pipe is in the foreground is used to heat the building and burns the only coal used on the property.

of $16 000 000 to $25 000 000. It is expected that the tonnage will increase greatly, as the lower grade ores can now be treated profitably. One mine has as high as 15 000 000 tons of low-grade ore blocked out.

High Efficiency in a Hydroelectric Plant

OBTAINED THROUGH UNIQUE DESIGN

J. W. Swaren

THE United States Reclamation Service of the Department of the Interior has been called upon to design and construct many installations in the course of its engineering operations. Under its jurisdiction have been built more distinctive hydroelectric plants than under the jurisdiction of any other group of engineers. Of these, the Cross Cut power plant of the Salt River project is probably the most unique from either an economic or an engineering point of view.

THE Salt River project lies in Arizona, north of the Salt River in a series of mesas, each mesa being served by a canal with its head at or near the river. The upper canal, known as the Arizona, skirts the mountains, and is the main artery from the Roosevelt Dam, supplying water for a number of subsidiary canals, as well as the upper mesa. The chief subsidiary canal is the Grand. As originally constructed, its head was near the Salt River and its nearest point approached within eight miles of the Arizona Canal. Water was carried into the Grand Canal by an auxiliary canal known as the "Cross Cut," with a total fall of 130 feet in the eight miles.

J. W. Swaren

Surveys of the intervening territory showed that a new cross-cut canal could be laid out along a profile to the east of a hill known as "Hole in the Rock," with 117 feet of the total fall in the last half mile. The terminus of the new Cross Cut Canal is about one mile from Tempe and eight miles from Phoenix, and almost at the exact geographical and load center of the entire Salt River project distribution system.

Consideration had previously been given to building a steam standby station for the purpose of improving the service in Phoenix and nearby towns, where quite a respectable motor load has been developed among cotton gins, refrigerating plants and similar industries. The possibility, however, of securing water power in such a favorable location led to an investigation of the merits of its utilization.

PROBLEMS ENCOUNTERED

The difficulties encountered were unusual, even for a hydroelectric installation. First, was the matter of stream flow, which is not dependent, except remotely, on the weather or run-off, but on the irrigation requirements of the lands below. It varies from 0 to 720 second-feet, the maximum carrying capacity of the main canal. The highest rate obviously is during the summer.

The physical characteristics of the water are most unusual and highly detrimental to the operation of hydraulic machinery. Silt is always held in suspension, at times to the full transporting capacity of the stream. The chemical characteristics are also unfavorable, as the water is strongly impregnated with salts, which precipitate in contact with iron and steel to an extent that interferes with the seating of valves or the operation of wicket vanes.

The climate and the geological formation are both adverse factors. The temperature of the air varies from 36 to 126 degrees F., making the expansion of one-half mile of pipe line a problem of some moment. The profile of the pipe line traverses a rock slope of such hardness that trenching would be prohibitive. Offsetting these rather extreme hydraulic conditions was the economy of abstracting power from water necessarily supplied to the Grand Canal, as well as the advantages of having a power house at the load center.

FOREBAY AND INTAKES

The terminus of Cross Cut Canal was expanded into a forebay, having a spillway 344 feet in length. The forebay, the headgate settings, pressure pipes, power house, including all water passages, transformer houses and switch rooms, are constructed of reinforced concrete, the whole structure being virtually a monolith.

The pipe line intakes are rectangular, tapering to circular sections, where a butterfly valve is set in each pipe line. Normally these valves are operated by hand, but emergency operation from the power house is possible through a pneumatic-oil system controlled by a compressed air line. This system provides for closure only and, with a pressure of 125 pounds in the air reservoir at the power house, the gate can be closed in 40 seconds.

The pressure pipes are designed for a maximum static pressure of 110 feet; both are seven feet in diameter, the east pipe being 2240 feet in length and the west pipe 2247 feet in length. The pipe lines are anchored to the rock by means of reinforced rods grouted in the drilled holes. After the pipe line structure was completed and the concrete seasoned it was covered with earth.

POWER HOUSE

The power house was built to conform to the topography of the site. The generator room is 176 feet by 42 feet. The entire station, which is 63 feet high on the tailrace side, is built on solid rock. It con-

sists virtually of two complete systems under one roof, each pipe line connecting to its units by a manifold without any provision for intercommunication. Each manifold supplies three main units, one exciter unit and one governor oil-pump unit.

TYPE OF WATER WHEEL

The chief technical feature of this installation is the unusual type of water wheel installed. The physical and chemical characteristics of the water have proven so detrimental to turbine installations on the other portions of the project that the wicket gates and runners require replacement every three or four years. With the ordinary types of impulse wheels under an operating head of only 111 feet, the maximum power that could be developed in a single runner unit would not be in excess of 400 hp. With 7000 hp available, it is obvious that units of 400 hp would result in an extremely unwieldly power house of high first cost per kw.

A vertical-shaft, single-runner, multiple-nozzle Pelton unit of 1000 hp capacity was finally decided upon.

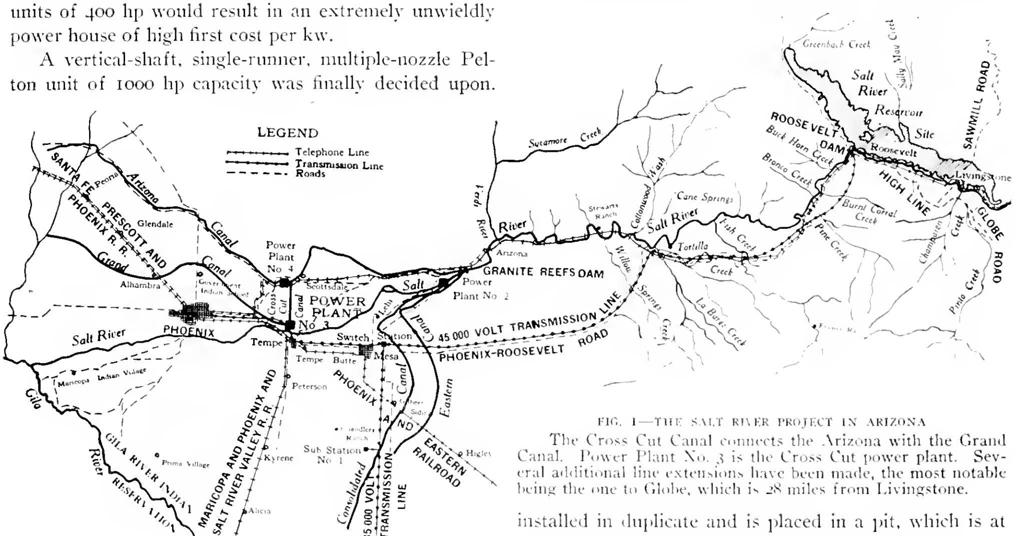


FIG. 1—THE SALT RIVER PROJECT IN ARIZONA

The Cross Cut Canal connects the Arizona with the Grand Canal. Power Plant No. 3 is the Cross Cut power plant. Several additional line extensions have been made, the most notable being the one to Globe, which is 28 miles from Livingstone.

This consists of a vertical-shaft unit with six nozzles set at equal distances about the periphery of the runner. The moving element is of sufficient strength to permit operation with any combination of nozzles from one to six. Changing the number of nozzles in accordance with the amount of water available or the load produces a practically straight-line efficiency curve. Variations less than one-sixth of the total load are taken care of by the deflectors, one for each nozzle. By this method of regulation there is no interference with the stream flow, a highly essential factor in this installation. The water for each nozzle is controlled by an oil-operated poppet-type valve set in the upper opening of the nozzle body. The operation of these valves is controlled by means of hand-operated pilot valves, the stems of which are threaded with an unusually small pitch. Quick opening or closing of the valves is prevented in this manner.

In order to avoid interference from high tail water, the pitch line of the runner is set three feet above tail water. This reduces the net head to 107 feet, requiring a wheel efficiency of 80 percent in order to meet the guarantee. During storm periods these units have been operated satisfactorily with tail-water clearance of 12 inches.

A single steady bearing set in a framework suspended in the bottom opening of the shaft well is used. Each steady bearing is grease-lubricated by an individual motor-driven oil pump set on the power house floor.

The total weight of the generator rotor and water-wheel shaft is 46 000 pounds, and is carried by a Kingsbury thrust bearing mounted on top of and supported by the generator frame.

GOVERNOR OIL SYSTEM

Pelton-Doble vertical-type oil-pressure governors actuate the deflectors. The governor oil equipment is installed in duplicate and is placed in a pit, which is at the center of the tailrace side of the generator room.

Each oil set consists of a Pelton-Doble water motor with a two-stage positive displacement rotary oil pump, mounted on the water motor shaft, one stage being placed on either side of the runner. Automatic control of the oil set is provided through an oil-operated needle nozzle governed by the height of the oil in the pressure reservoir. The pressure reservoirs of each set have a capacity of 400 gallons, while the steel sump tanks are of 5000 gallons capacity. The pump and the filter of the lubricating oil system are likewise placed in this pit. The storage tank for the lubricating system is set under the roof of the transformer house.

GENERATORS

The six main units are three-phase, 25 cycle, 11 000 volt Westinghouse generators, rated at 875 k.v.a. at 80 percent power-factor, and operate at 94 r.p.m. These are of the umbrella pattern revolving field type. Eleven kilovolt, cambric-insulated, single-conductor cables in

paper conduits embedded in the concrete run from the generators to the switching apparatus on the rear wall of the switch house.

The exciters are driven by Pelton-Doble water wheels of a design identical with that of the larger units, and are rated at 200 kw, 125 volts, when operating at

FIG. 2—SPILLWAY OF THE CROSS CUT CANAL

150 r.p.m. Kingsbury thrust bearings are mounted on top of the exciter frame in much the same manner as in the case of the main unit. The equalizer switches are also mounted on the exciter frame.

SWITCHBOARD EQUIPMENT

The switchboard is on a reinforced concrete gallery, and consists of twelve three-section panels, six generator panels, one totalizing panel, two 11 000 volt feeder panels, one 45 000 volt panel and two transformer panels. At one end of the gallery is an auxiliary switchboard for the exciter units and direct-current service. This switchboard is set at right angles to the main switchboard. The generator panels carry two ammeters and one wattmeter on the vertical panel. The bench panel carries the manual operator for the selector switches and the governor variation controller, as well as the customary bus-bar plan and pilot lamp lenses.

Single-throw, electrically-operated oil switches are used for the selector switches, thus permitting each generator to feed into either bus. The base panel carries two single-phase overload relays and the hand wheels for the generator rheostats. The grids for the rheostats are mounted in the transformer room immediately back of the switchboard, and are arranged for forced ventilation during hot weather. As a reinforced concrete wall intervenes between the grids and the generator room, the heat emanated does not affect the temperature of the generator room, a feature of some moment in view of the very high air temperatures during the summer months. The synchroscope, voltmeter, power-factor meter and frequency meter are mounted on a swinging bracket at the end of the switchboard. The totalizing panel carries on its back panel two graphic voltmeters and two graphic wattmeters. The bench panel carries the voltmeter plugs and a resistance controller for the Tirrill regulator, while the base panel has two recording wattmeters of switchboard type.

Each of the transformer panels controls two sets of transformers. The bench panel carries eight manuals for operating the single-throw, remote-control, electrically-operated oil selector switches, which permit either or both sets of transformers to be connected to either or both bus-bars. The base panel carries four single-phase overload relays, two for each set of transformers. The feeder panels are each arranged to handle two circuits. Panel No. 1 controls a 11 000 volt line running to the Chandler substation, and is also the receiving panel for a 1000 k.v.a., 11 000 volt line from the Arizona Falls power house. Panel No. 2 controls the 11 000 volt circuit feeding the Mesa substation. The back of each feeder panel carries six ammeters, while the bench panel has four manuals for controlling the single-throw selector switches. The base panel is fitted with four single-phase overload relays.

The high-voltage panel is designed to handle two lines, known respectively as the "North" and "South" line, connecting these lines to either of two high-voltage bus-bars. The back panel carries seven ammeters, one ammeter in each lead of the high-voltage circuit, and the seventh ammeter in the grounded neutral. The bench panel has four manuals for controlling the single-throw selector switches. The base panel is blank.

The auxiliary board consists of three panels. Nos. 1 and 2 are the exciter panels carrying a voltmeter, an ammeter and a double-pole, double-throw main switch, and two manuals for generator field switches. No. 1 carries in addition a double-throw switch for controlling the bus for the electrically-operated apparatus, while the No. 2

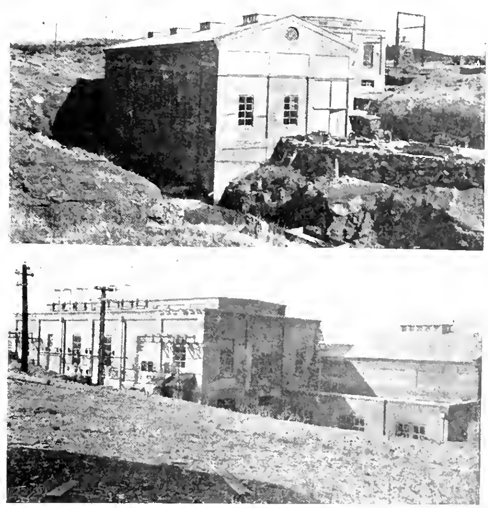


FIG. 3—CROSS CUT POWER HOUSE

panel carries a double-pole, double-throw switch controlling the station lighting panel. The No. 3 panel is the regulator panel and has mounted on it a compound Tirrill regualtor, consisting of two sections of ten points each, as well as two manuals for the double-pole, double-throw generator field switches, which are operated by a

remote-control, bell-crank manual system. The direct-current busses are in duplicate and are carried on a pipe framework with porcelain supports.

Both switchboards are made of black Vermont marble. All remote control and instrument wiring of the main board is carried on the back of the board, which is entirely housed by a sheet steel covering attached to the angle-iron frame. This isolates the wiring of each panel, effectually preventing interference and greatly lessening the fire hazard.

SWITCH HOUSE

The switch house is constructed in two stories, the lower story given over to the low-voltage switches and the upper story to the high-voltage switches.

The low-voltage switchroom is divided into three bays; the generator leads and the outgoing leads are brought into the middle bay. Air-break disconnecting switches are mounted on curtain walls suspended from the ceiling, while the oil selector switches are mounted on curtain walls built up from the floor. These curtain walls are four inches thick, reinforced with three-fourth-inch rods, and were poured monolithic with the floor and walls of the building.

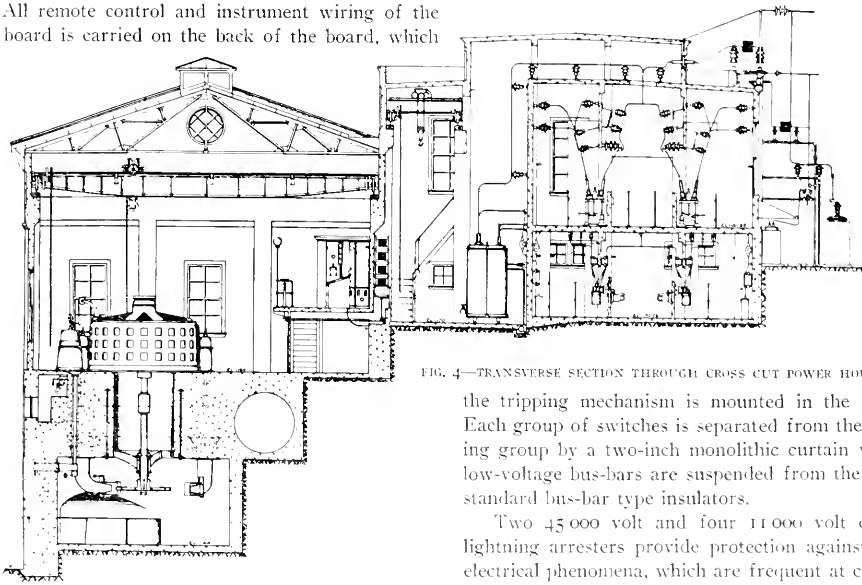


FIG. 4—TRANSVERSE SECTION THROUGH CROSS CUT POWER HOUSE

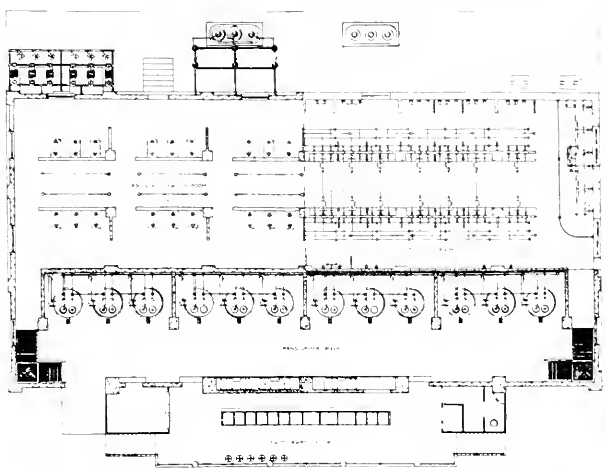


FIG. 5—PLAN OF TRANSFORMER AND SWITCH ROOMS AND SWITCHBOARD GALLERY

The bus-bars are of the double-loop type, and are mounted in the outer bays, thus providing a wide separation for the two sides of the bus-bar system. The contactors and oil tanks are mounted in the outer bay, while the tripping mechanism is mounted in the inner bay. Each group of switches is separated from the neighboring group by a two-inch monolithic curtain wall. The low-voltage bus-bars are suspended from the ceiling by standard bus-bar type insulators.

Two 45 000 volt and four 11 000 volt electrolytic lightning arresters provide protection against transient electrical phenomena, which are frequent at certain seasons of the year. An oil-testing set is set up in the low-voltage switch room. Periodic tests of transformer oils and switch oils are conducted.

The current and potential transformers are set in open front cells, along the back wall of the switch house, the potential transformers being placed on the floor and the current transformers mounted on the wall.

All disconnecting switches are mounted on a framework supported by a four-inch reinforced curtain suspended from the ceiling, while the oil switches are set on the floor. The high-voltage bus-bars are carried, two on the wall, and the third suspended from a curtain. The 45 000 volt, 300 ampere, single-phase, remote-control switches are electrically-operated, with automatic excess current trips actuated by series relays.

Separation of the busses by the width of the switch house and the group method of switch arrangement permit any circuit or group of equipment to be isolated physically as well as electrically when inspection is necessary.

TRANSFORMER EQUIPMENT

The transformer room is between the generator room and the switch rooms proper. It contains four

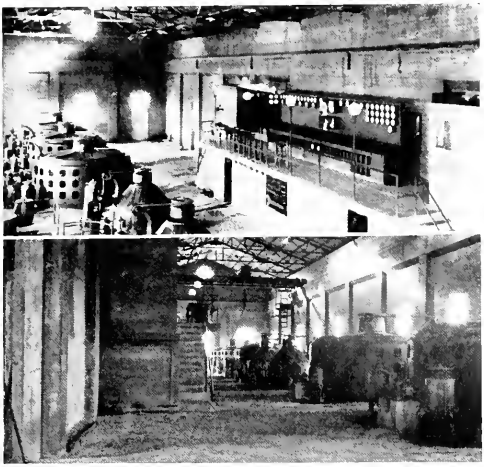


FIG. 6—INTERIOR VIEWS OF POWER HOUSE

groups of three single-phase, 500 k.v.a., 23 100/10 500-11 000-11 500 volt transformers, connected in delta on the low-tension side. Each group is in a cell of four-inch curtain walls reinforced with twisted rods, with one side open. Cooling water is obtained from a tower at the rear of the power house. The water flows by gravity through the transformers and into a sump built in the machine shop. A centrifugal pump elevates the water from this sump into the cooling tower, where it is discharged through spray nozzles. Make-up water is obtained from a nearby well.

TEST

In order to determine the bonus or penalty in accordance with the terms of the contract, a test was run on January 16, 1916, for the purpose of determining the actual efficiency of the water wheels. One unit was selected for test. The factory test of the generator was accepted as a means of determining its mechanical input.

An unusual method of loading the generator under test was used. One generator was reversed in phase direction and connected to an isolated bus, to which was connected the unit to be tested. On starting up the unit under test, the reversed generator was brought up to speed as a synchronous motor. Water was then turned into the nozzles of the motoring generator and, striking into the bowls of the backward-turning buckets, it provided a brake capable of accurate control. In all, this generator and water wheel were operated backward for two days.

The water was measured in the tailrace by means of a weir, with current meters for determining the velocity of approach in both the forebay and the tailrace. The head was determined by laboratory type pressure gages, while the electrical output was determined by precision type instruments. The final computation showed an over-all efficiency from headwater to tailwater of 79.26 percent, or 4.26 percent in excess of the contact requirements, and equivalent to a water wheel efficiency of 83 percent, which compares very favorably with a Francis turbine unit of the same size and operating under similar head.

In spite of its completeness and the unusual amount of apparatus installed in order to insure maximum flexibility, the unit cost of the entire station was comparatively low, being slightly less than $88 per k.v.a. maximum rating. The plant has proven very satisfactory in operation, one operator on each eight-hour shift proving sufficient. In addition, a chief operator in general charge and a janitor are kept on duty, making a total of five men as the entire operating crew.

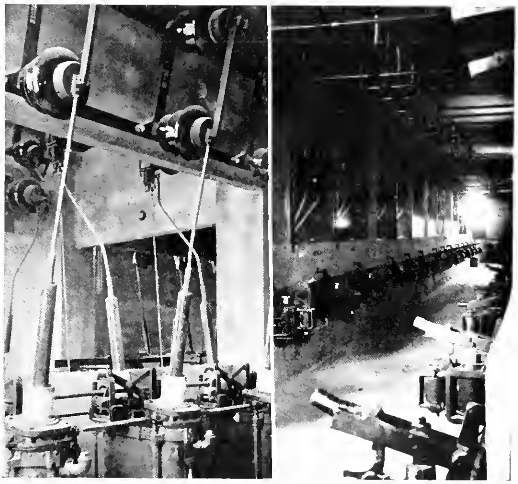


FIG. 7—HIGH-VOLTAGE OIL SWITCHES AND OVERLOAD RELAYS (LEFT); AND LOW-VOLTAGE SWITCH ROOM (RIGHT)

Electrical Precipitation*

ITS THEORY AND APPLICATION AT THE INTERNATIONAL SMELTING COMPANY'S PLANT, MIAMI, ARIZONA

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When a gas is in an ionized condition and passes an electrostatic field its ions begin to travel at a high velocity in the direction of one or the other of the electrodes causing the field. If the electrodes are charged to a high potential they become the ionizing agents as well as the source of the propelling force. These highly charged ions are continually bombarding any solid particle that may be in the field and impart a charge of like potential to the particle, which in turn begins to travel toward the electrode of opposite polarity. If one of the electrodes is a sharp point or a small wire, a greater stress is set up, resulting in greater ionization from this electrode only. Thus the gas receives a static charge of the same polarity. A striking illustration of the ionization due to points is shown by the old experiment of blowing out a candle by means of a highly charged needle.

Practical advantage is taken of these principles in electrical precipitation. The gases to be treated are caused to traverse metallic tubes at a velocity not greater than 12 feet per second. Each of these tubes becomes an electrode, while the other electrode is formed by a fine wire stretched along its central axis. A unidirectional potential of from 25 000 to 250 000 volts is applied, charging the solid or liquid particles in the gas and causing them to be deposited on the inner surface of the tube. The dust is collected at intervals by vibrating the tubes and thus shaking the dust down into bins. At these times both the current and the gases are shut off from the section of tubes being cleaned.

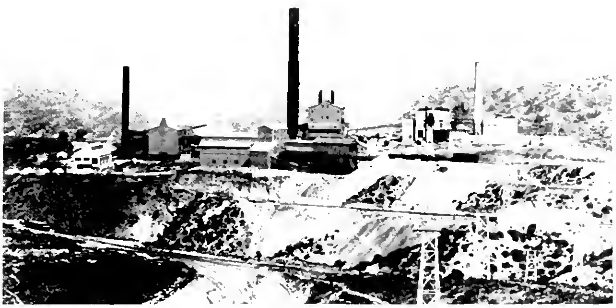


FIG. 1—PLANT OF THE INTERNATIONAL SMELTING COMPANY
The roaster plant containing the precipitation equipment is the central building with the small chimneys immediately to the right of the central tall stack.

HISTORICAL

That dust suspended in gases could be removed by electrical discharge was suggested nearly a century ago. In more recent years Sir Oliver Lodge rediscovered the same phenomena and suggested its application to purifying the atmosphere and eliminating soot or other objectionable matter from smoke. The first attempt to use the principle commercially was made at the Dee Bank Lead Works in 1885. Wimshurst influence machines were used as the source of electrical energy. These machines lacked the requisite capacity and stability of potential, and hence the first patents were allowed to expire without successful use. Twenty years later Sir Oliver Lodge again revived interest in the subject by patenting the use of the new mercury arc rectifier as applied to the electrical precipitation of suspended particles. It remained, however, for Prof. F. G. Cottrell, of the University of California further to develop the process. Following extensive laboratory experiments, he succeeded in having his invention installed in the DuPont Powder Company's plant at San Francisco for precipitating sulphuric acid mists. The process was soon after adopted by the Selby Smelting & Lead Company, at San Francisco, whose chimney gases had become a nuisance because they contained so much sulphuric acid, arsenic and lead salts.

Preliminary experimentation was necessary at both of these plants and many disappointments and obstacles were met and overcome before these plants were operating successfully. Electrical precipitation is now used or being installed at the following plants: Washoe Smelter, Anaconda, Mont.; Garfield Smelter, Garfield, Utah: Raritan Refinery, Perth Amboy, N. J.; Omaha Smelter, Omaha, Neb.; Goldschmidt Detinning Company, Chicago, Ill.; International Smelter, Tooele, Utah, and the Trail Smelter in British Columbia. At most of these plants the recovery of copper, gold, silver or lead values is sought. At Anaconda electrical precipitation is used to collect white arsenic or As_2O_3. Two treaters in series are used and the dust is separated from the arsenic by fractional precipitation. The gases enter the first

*A small part of this article originally appeared in an article by the author in the *Minnesota Engineer*.

treater hot and the dust is collected. By admission of air the gases are then cooled from 310 to 90 degrees C., and in the second heater pure white arsenic is collected. Fractional precipitation thus eliminates the refining furnace formerly necessary. At Anaconda another very

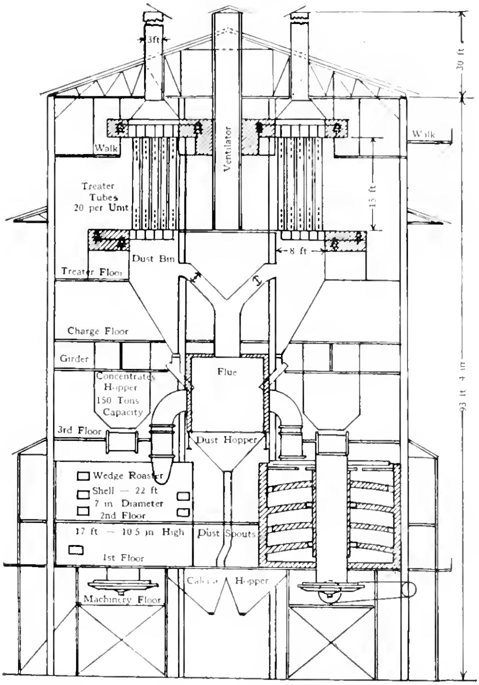


FIG. 2—PRECIPITATION PLANT OF THE INTERNATIONAL SMELTING COMPANY

Treating the gases from the roasting furnaces.

large installation is also being made to handle the gases from the roasters.

At the Bureau of Mines station at Pittsburgh an interesting installation is used to precipitate soot from boiler gases. One of the earliest plants was built by the Riverside Portland Cement Company in California, where 900 000 cu. ft. of gas per minute are being treated and about 90 tons of cement dust precipitated per day. The wide application of the process is also shown by a recent installation for the precipitation of powdered food, such as powdered milk or cream and powdered eggs; also in the removal of tar from illuminating gas and recovering chlorine in bleaching-powder works.

INSTALLATION AT MIAMI

Two precipitation plants are installed at this smelter, one of which treats the gases from the roasting or drying furnaces and the other treats the converter flue gases. The main object of both of these installations is to recover the copper which would be lost if these gases were discharged directly into the atmosphere. At most modern copper plants this saving has been accomplished by building enlargements in the flue, or large dust-settling chambers. But experience has demonstrated that a more complete recovery may be obtained by electrostatic precipitation.

A cross-section through the roasting plant is shown in Fig. 2. The precipitation apparatus is mounted over the drying furnaces and is provided with 12 chimneys, 30 inches in diameter by 30 feet high, for discharging the treated gases into the air. This arrangement was chosen over the alternative scheme of bringing the gases down to treaters on the ground level. A single chimney conducts the treated gases away and provides draft.

The electrode tubes are 13 inch welded steel pipes 15 feet long. They are belled outward or "Vanstoned" at each end to reduce the brush discharge at these points. Twenty of these tubes, together with other accessories, make up a unit, which has its own gas intake, chimney and electrical connections. The gas can be shut off from one of these units by means of dampers, the switches opened and the tubes vibrated by means of mechanical hammers to shake the collected dust into a hopper beneath. Twelve such units comprise this plant.

The other and ungrounded electrode is a No. 20 nickel-chrome-steel alloy wire. A light steel frame, supported on insulators, enters the hood through glass windows. One such frame is used at the top to support the electrode wires, which are spaced at the bottom by a similar frame. A five-pound weight at the bottom of each wire holds it taut.

The gas consists almost entirely of air with a high percentage of water vapor and carbon dioxide, at a temperature of about 80 degrees C. The gas also is permeated with a fine dust carrying about 25 percent copper. About five tons of this dust are collected per day. The efficiency obtained is practically 100 percent; no visible material can be seen escaping from the exit stacks under normal operation.

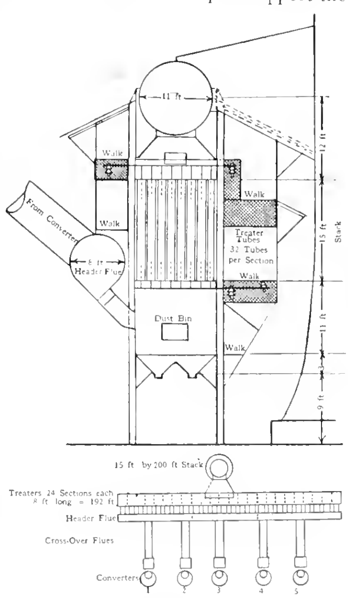


FIG. 3—PRECIPITATION PLANT AT MIAMI, ARIZONA

Treating the converter flue gases directly.

No trouble is experienced in the operation of this plant, provided a temperature is maintained sufficiently

high to prevent the condensation of moisture in the tubes. Such moisture would not only make the precipitate a sticky mud, which would be difficult to dispose of; but, together with any sulphur trioxide which is certain to be present in small quantities, would hasten the destruction of the treater itself by corrosion.

CONVERTER PLANT

This gas differs from the roaster gas by having the higher temperature of about 400 degrees F. and by being dry and containing a large percentage of SO_2 and SO_3. In order to treat the larger volume of gas the units were made to include 32 thirteen-inch tubes each. The five converters deliver their gases to one common header flue. The 24 units of the precipitation plant draw their gas from this flue and discharge upward into another common header, which leads to a 15 by 200 foot chimney. As in the dryer plant, the collected dust is shaken down into bins located over standard-gauge tracks. A covered and dust-tight larry car transports the dust directly over the reverberatory charge hoppers, through which the dust passes into the furnaces. The velocity of the gas is six feet per second, based on a total volume of 250 000 cu. ft. per minute.

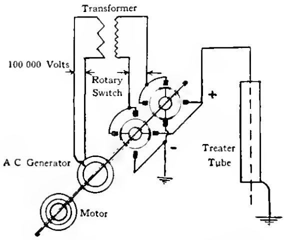


FIG. 4—ELECTRICAL CONNECTIONS OF APPARATUS
Used in the converter plant of Fig. 3.

The principle change made in the treaters since the original installation has been the housing in of the treater units with corrugated iron placed about each set of tubes. The reasons for doing this were three-fold:—First, it was found that the wind chilled the tubes on one side, which caused most of the gases to pass up the tubes on the other side of the treater. This unequal distribution of gas is cumulative, the hot tubes becoming still hotter due to the large volume of hot gases going through them, while the cold ones soon cooled off entirely and took no gas at all. This effect is being avoided in the latest installations by adopting "down draft" tubes, in which this effect of chilled tubes is self-corrective instead of being cumulative. Second, the chilling of the dryer gas condensed moisture and sulphuric acid on the tubes, as referred to above, is entirely obviated by housing them in. Third, in the converter plant the maximum of draft is desirable and can be obtained only by keeping the gas entering the main stack as hot as possible.

ELECTRICAL APPARATUS

In order to obtain a unidirectional current at from 60 000 to 100 000 volts, a rotary switch is used to rectify the current of a high-potential transformer. Two arms carrying a segment of copper plate at each end are mounted on a shaft at right angles to each other, as in Fig. 4. The arms are insulated from the shaft and from each other and revolve between the adjustable brushes, which clear the plates by a half inch. Electrical synchronism is obtained by driving an alternating-current generator directly connected to the switch. This generator furnishes the primary current of the transformer as well as the means of voltage control by variation of field resistance. The generators and transformers each have a capacity of 15 k.v.a. There are eight of these electrical sets operating at about two-thirds capacity, besides two spare units. This means a power consumption of 16 watts-seconds per cubic foot of gas treated.

Electric Mine Hoists

GRAHAM BRIGHT

WHEN the various coal and metal mines in this country each had their own isolated power plants there was little incentive to install electric hoists. The boiler plant had to be of the same capacity whether the hoist was driven by a steam engine or a motor taking power from a generating plant of which the boilers were a part. The boilers, moreover, had a great overload capacity due to their storage capacity, while a generating system might be very seriously disturbed by the sudden peak loads which are characteristic of most hoisting plants. The advent of central station power has changed the situation to a marked degree. It took the mining companies some time to realize that they could purchase power from a central station cheaper than they could make it themselves. The central stations were partly to blame for this, as they were not sufficiently active in presenting convincing arguments and rate schedules to the mining companies. The use of central station power has now become so widespread throughout mining communities that there is no longer any question as to the feasibility of its use and the benefits obtained.

In some cases steam hoists are converted into electric hoists by removing the connecting rods, and coupling or gearing a motor to one or both of the crank discs. Care should be taken in making a change of this kind to be sure that the hoist parts are sufficiently strong to stand the strains that may be obtained when using a motor. In many cases the strains are considerably in excess of the maximum that could be obtained when using steam power. If the hoist is old and in poor condition it is usually much better to scrap or sell it and purchase an entirely new electric hoist.

Several systems are in use for electric hoisting, and the proper one to use depends largely on the power conditions and the characteristics of the hoist itself. The

fact cannot be emphasized too strongly that each hoisting installation is a separate problem in itself, and no general rules can be laid down to determine the proper system and capacity of the equipment necessary.

Purchased power is usually available at 2200 or 440 volts, three-phase, 60 cycles and, when the rope speed is not too high and the power system can stand the peak loads imposed, the alternating-current wound rotor induction motor is the most satisfactory in regard to first cost, operating conditions and power consumption. The capacity of hoist motors ranges from 25 to 1800 horsepower. For the small sizes up to about 150 horse-power the standard drum controller is generally used. For the intermediate sizes, from 150 to 500 horse-power, the magnetic switch type of controller is used. This controller has magnetic switches in both primary and secondary controlled by a master controller. For motors larger than 500 horse-power, the liquid rheostat is used in the secondary, while magnetic switches are used in the primary for reversing. The reason for using the liquid rheostat for large motors is that the currents become too heavy for magnetic switches and a much smoother control is obtained. In most cases the alternating-current motor is geared to the drum shaft by means of single reduction herringbone gears. These gears have helped the hoisting situation to a very marked degree in that much higher gear reductions can be utilized than is advisable with ordinary spur gears. With spur gearing the maximum reduction that can be obtained with good practice is about 8 to 1. With herringbone gears a maximum reduction of 15 to 1 has been obtained with little difficulty. This higher gear reduction allows the use of a fairly high-speed motor with a single gear reduction. The high-speed induction motor is cheaper and has a better efficiency and power-factor than a slow-speed motor.

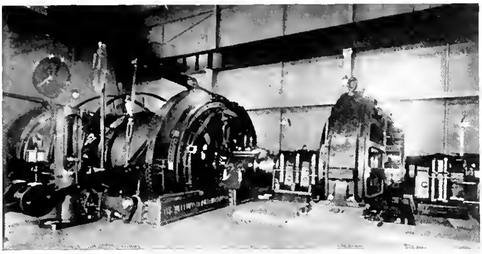


FIG. 1—HOIST INSTALLED AT THE NORTH BUTTE MINING COMPANY, BUTTE, MONTANA

This is the largest electric hoist in America.

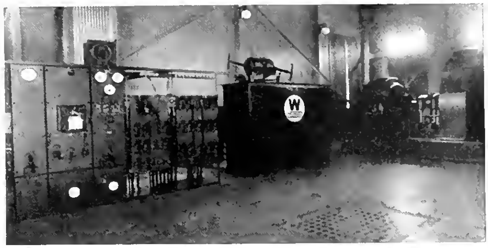


FIG. 2—MOTOR-GENERATOR FLYWHEEL SET, LIQUID SLIP REGULATOR, AND CONTROL PANELS OF THE HOIST SHOWN IN FIG. 1

It has been found that the best practice for coupling the motor to the drums is for the electrical manufacturer to furnish a two-bearing motor and for the hoist builder to connect this motor to the hoist through a flexible coupling.

Where direct-current power is available the same general type of control is used to vary the speed of the motor by inserting resistance in the armature circuit. Direct-current hoist motors larger than 300 horse-power are seldom used with a constant-voltage system. The only disadvantage of using a slow-speed direct-current motor is the first cost, its operating characteristics being as good, if not better, than the high-speed motor. The shunt motor, series motor, or compound motor with rheostat control, is as a rule only used where alternating-current power is not available.

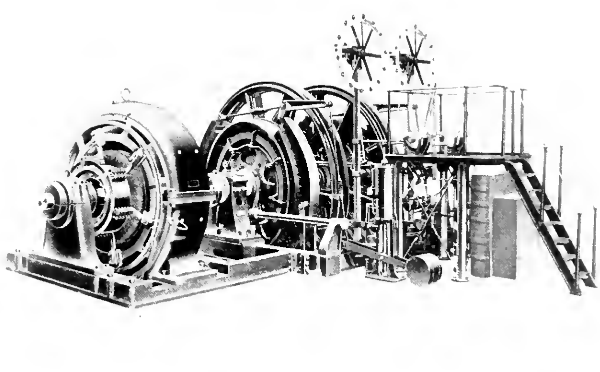


FIG. 3—HOISTING SET INSTALLED AT THE HECLA MINES AT BURKE, IDAHO

The majority of coal mines and smaller metal mines use the alternating-current wound-rotor motor for hoisting. Where the power system will not permit hoisting loads the Ilgner system is used to advantage. This system uses a separately-excited direct-current motor with constant field excitation for the hoist motor. The motor is permanently connected to a separately-excited, variable-speed direct-current generator, which in turn is driven by a wound-rotor induction motor. A flywheel is mounted with this motor-generator set, and a liquid slip regulator is so connected into the secondary of the wound-rotor motor that resistance is inserted in the circuit if the

load on the primary exceeds a certain predetermined value.* The insertion of this resistance causes the set to slow down and the flywheel to give up some of its energy. The load on the induction motor is kept fairly constant, while the peak loads on the generator during the accelerating period are supplied by the flywheel. With this system the control is much superior to the alternating-current system using only the wound-rotor induction motor. Any given position of the control handle means a definite speed independent of the load. This makes automatic control possible, while with either alternating-current or direct-current hoist motors using rheostatic control the speed not only depends on the position of the control handle, but also on the load. For this reason, automatic control when using an induction motor or direct-current motor with rheostatic control is very difficult to obtain.

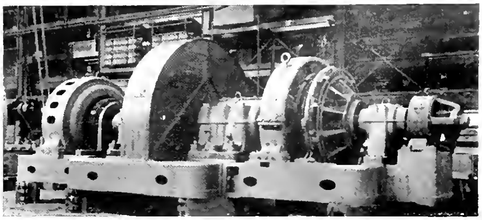


FIG. 4—MOTOR-GENERATOR FLYWHEEL SET FOR ILGNER HOISTING SYSTEM

Controlling the hoist motor speed by varying the field strength of the direct-current generator of a motor-generator set is known as the Ward Leonard system. During the retarding period the hoist motor often acts as a generator, and the energy required to stop the moving parts, including the load, drums, cages, skips, ropes, sheave wheels and rotating parts of the hoist motor is pumped into the flywheel through the generator acting as a motor instead of being wasted in heat, as is the case with rheostatic control.

The Ilgner system is used in coal mines where equalization of power is desired and at the same time where the rope speed is high and the cycle short. The hoist motors in actual service vary from 500 to 1300 horse-power. From metal mines the Ilgner system is used where entire or partial equalization is desired, and differs from coal mine practice in that the mines are usually much deeper, the rope speed higher and the loads heavier. The hoist motors in actual service range in capacity from 500 to 4000 horse-power. In most cases the hoist motor is directly connected to the drums, which simplifies the arrangement and is much better mechanically due to the absence of gears.

Owing to the long cycles, a heavier flywheel is required in metal mines than in coal mines. The Ilgner system is installed mainly in the west and southwestern parts of the United States. In the Michigan field there are a few Ilgner sets, but the general tendency is toward the use of the wound-rotor motor even for the larger hoists.

Where a large power system exists and peak loads are allowable, the Ward Leonard system is frequently used without the use of a flywheel on the motor-generator set. The wound-rotor induction motor is replaced by a synchronous or squirrel-cage induction motor, and the peak loads on the hoist motor are carried through to the power system with the losses of the various machines added. With the Ilgner system, the capacity of the alternating-current motor need only equal the average load required over the entire cycle. Where a synchronous or squirrel-cage induction motor is used without a flywheel, the capacity of the motor is determined by the square root of the mean squared horse-power over the entire cycle. This often results in the capacity of the motor being more than twice that required by the Ilgner system using a flywheel.

The Butte & Superior Copper Company is installing an Ilgner hoisting equipment which will have an ultimate capacity of 4000 horse-power in the hoist motors. The wound-rotor induction motor driving the flywheel set will have a capacity of 2000 horse-power. If a synchronous motor-generator set were used without flywheel, the synchronous motor would have to have a capacity of not less than 4500 horse-power. During normal operation with the flywheel set over a given cycle, the load on the induction motor will not vary much over 100 horse-power. Using the synchronous motor without flywheel, the load on the synchronous motor during one cycle would vary from about 9000 horse-power positive during the accelerating period to about 5000 horse-power negative during the retarding period. This makes a total variation of 14 000 horse-power during each cycle. It is needless to say that there are few power systems in the country that would care to assume a load of this character, owing to the bad effect it would have on the regulation of their lines.

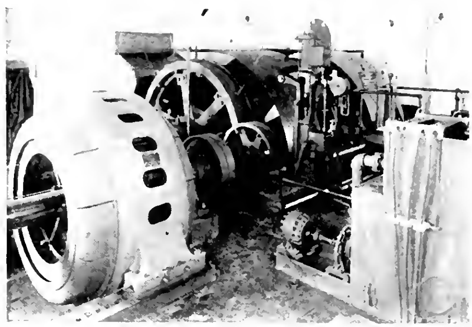


FIG. 5—LARGE ALTERNATING-CURRENT HOIST WITH LIQUID RHEOSTAT
Installed in the anthracite coal region at one of the mines of the Lehigh Coal & Navigation Company. The hoist motor has a nominal rating of 750 hp and a maximum continuous rating of 1125 hp.

*See article on "Liquid Rheostats," by Mr. W. E. Thau, p. 684, and on "Control for Mine Hoists," by Mr. Graham Bright, p. 704, in the JOURNAL for Dec., '14; article on "Power Requirements of Electric Hoisting Plants," by Mr. W. Sykes, p. 144, Mar., '14, and p. 274, May '14; and article on "The Electrical Equipment of the Granite Mountain Hoist," by Messrs. G. B. Rosenblatt and W. Sykes, p. 229, May, '16.

The Ward Leonard system using a synchronous motor is more efficient than the Ilgner system, especially where hoisting is not constant, due to the absence of the flywheel loss. A flywheel of 100 tons weight will have a friction and windage loss of approximately 100 horse-power. The Ward Leonard system of control is particularly valuable when handling men. During a cycle in a deep mine, the power will often change from positive to negative during constant-speed operation, due to the counterbalancing effect of the cable. It often happens that the weight of the unbalanced cable is considerably greater than the load to be hoisted. At the North Butte hoist, and also at the Butte & Superior hoist, the weight of the unbalanced cable will be about 50 percent greater than the load at the maximum depth. With rheostatic control it would be very difficult to maintain a constant speed throughout the cycle, while with the Ward Leonard system a given position of the control handle means a certain definite speed, irrespective of the load or position of the skip or cages in the shaft. The Ward Leonard system of control also lends itself to the application of safety devices very much better than does the rheostatic control. A positive slowdown can be provided which gradually pushes the control handle to the off position as the loaded cage approaches the surface. With the Ward Leonard system this scheme will produce a positive slowdown, so that if geared limit or hatchway switches are provided there will be no question as to the ability of the braking system to stop the hoist if an overwind takes place. With rheostatic control this positive slowdown cannot be produced since, when the power is negative, a movement of the control handle toward the off position will increase the speed instead of diminishing it. A geared limit switch or a hatchway switch is useless unless a positive slowdown can be obtained.

The first Ilgner hoist in North America was installed at the El Oro mines in Mexico in 1905. The first Ilgner system installed in the United States was at the Hecla

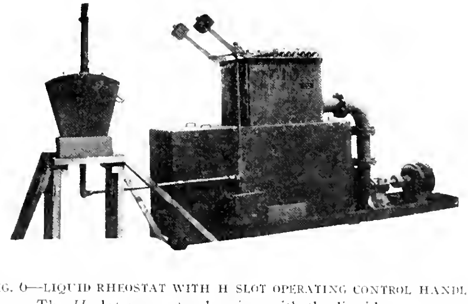


FIG. 6—LIQUID RHEOSTAT WITH H SLOT OPERATING CONTROL HANDLE
The *H* slot prevents plugging with the liquid up or resistance low.

mines at Burke, Idaho. This equipment is illustrated by Fig. 3 and is still in successful operation.

Most of the mining equipments in this country using the Ward Leonard system of control also use the flywheel motor-generator set. In South Africa most of the mining equipments using Ward Leonard control do not use the flywheel and have synchronous motors driving the generators.

For hoists up to 1000 horse-power a face plate or drum type of control is used to control the fields of the generators. This controller is required to handle a current of not over 50 amperes at 250 volts. Automatic relays can be provided which prevent too rapid acceleration or retardation due to careless operation of the control handle. For the larger hoists a number of magnetic switches are used to handle the field current of the generator, and these are controlled by a master controller. The current to be handled seldom exceeds 60 amperes at 250 volts, while the main current between the hoist motor and generator may go as high as 7500 amperes at 600 volts.

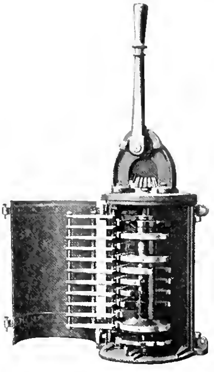


FIG. 7—DRUM-TYPE HOISTING CONTROLLER

Sometimes for an emergency speed condition the last few notches on the controller work on the fields of the motor, thereby increasing the speed after the fields of the generator have reached their maximum value. Automatic acceleration and retardation can be easily applied when using the magnetic type of control.

For different types of hoists the drum shapes vary widely. The most popular shape of drum, however, is the straight cylindrical type, which is used in the majority of cases. The advantage of the cylindrical type over other shapes is that it is easier and simpler to build, weighs less and produces less rope wear when compared with the other shapes. The conical drum is used to reduce the peak loads during acceleration, but in many cases shows but little advantage over the cylindrical type of drum. A combination of the cylindrical and conical type of drums has been used to a considerable extent. Acceleration and retardation takes place with the ropes on the cylindrical portions, while at constant speed of the drum the loaded cage is ascending the cone while the empty cage is descending the cone. For mines of moderate depth, using a fairly high rope speed, this type of drum will sometimes show considerable advantage in peak loads and capacity of equipment over the cylindrical drum. For the deep metal mines the cylindrical drum is almost imperative, since it becomes necessary to wrap the cable in two or more layers.

For intermediate depths up to 3000 feet the reel type of hoist using a flat rope is popular in some of the metal-mining districts. The flat rope is, however, expensive to maintain, and the larger mining companies are discarding it and using the plain cylindrical drum.

The value of coal and the cost of power in an isolated plant have been increasing rapidly during the last few months, and this should supply quite an impetus to the installation of electric hoists using purchased power.

Measuring Maximum Demands

S. G. Hibben

It is well known by the companies that supply electrical energy that, in justice to their customers, all charges should be proportional to the total service costs. It is no longer sufficient to expect the consumer of variable amounts of power to pay only for his kilowatt-hour consumption, any more than it is reasonable on the part of the consumer to expect the central station to maintain in idleness such an equipment as the consumer may call into service only a small proportion of the total time.

Due to the uncertainties and fluctuations of the demands that the consumer makes upon the supply, the cost of supplying electrical energy bears no direct relation to the actual amount of energy supplied. To this the average consumer has given but little thought. He has had no occasion to consider that the central station must invest money in generators, boilers and distributing systems, all of sufficient capacity to supply, without notice, the maximum possible energy that he may at any hour demand, and on which investment the returns must be constant and dependable, whether the plant is overloaded or idle.

It is not the consumer's installed capacity, but the maximum use of this capacity that affects the central station costs. "Preparedness to supply" governs cost as much or more than "supplying." In short, electrical energy must in justice be considered a service, as well as a commodity which is being purchased. If this is true, then there should be a means of measuring or evaluating the electrical energy in addition to measuring the commodity, as has been done in the past, by the common integrating watthour meter. It is for this purpose of measuring "service" that the maximum demand meters have been developed. The use of demand meters or the charges for excess loads of comparatively short duration are, of course, in no way directed toward the curtailment of the total amount of energy consumption. Their use is either to afford the central station a measured record, and therefore an exact basis for the fixing of equitable charges, or to indicate to the consumer the variations of his load, and consequently aid him to smooth out its peaks. In fact, where customers will exercise care to confine their heaviest use of energy to certain off-peak periods of the day, the supplying company may charge a special low rate for such service, and the result will be that through the use of recording demand meters there will be a premium and not a penalty placed upon the extended use of electrical energy.

Several well-known schemes of fixing approximate charges for the consumer's maximum demands have been in practice—some partially successful, some rather unsatisfactory, many tending to complicate or discourage the extended use of electrical energy.

In one method there is a fixed monthly charge based upon the total connected load, or upon a certain arbitrarily determined percentage of it. Now if consumer *A*, with the same number and size of motors as consumer *B*, can use his machines at full load only a fraction of the time that *B* does, and yet at times uses them all simultaneously, whereas *B* never uses more than 75 percent of his machines simultaneously, then with the same energy charge and the same fixed demand charge, based upon the installed horse-power, there is obviously an injustice in the rates and an inequality of return. Instances of this sort would require a study and an empirical rate for each individual case, with the chances of consumer *B* paying excess to make up for deficiencies in charges made against *A*.

In another method use is made of devices that interrupt the service at a predetermined maximum load. Such interruptors, by limiting the service, prevent the consumer from using an excess load even when he is willing to pay an extra amount for the unusual demand.

Still another method has been to install a maximum indicator temporarily and record the fluctuations of an individual consumer's load for a short time. After that it is assumed that there will be similar recurring cycles of demand, and the service charge, or demand charge, therefore, is based upon this brief record. This is certainly more exact than a fixed charge based upon some value of connected horse-power, but is open to criticism, since very few large power demands pass through exactly parallel cycles, and the record is, therefore, not always typical. A demand meter permanently installed on all large loads is the modern way of arriving at a charge for unlimited energy and service that can be based upon exact measurements.

Logically, everything points towards the reasonableness of an instrument to measure maximum demand. The next question is, "How shall this demand be measured?"

Two of the difficulties with which the manufacturer has had to contend in the design of demand meters have been the lack of common practice in the formulation of demand contracts by operating companies, and the absence of a commonly accepted definition of "maximum demand." The following quotations from recent contracts illustrate demand definitions:—

> "The consumer will be billed each month on the maximum demand taken during the month, but in case of decreased load, this demand will not be taken as less than 75 percent of the highest maximum demand previously established."

"When a graphic recording maximum demand meter is used, and the installed capacity is 100 hp, or less, a sustained peak of one minute will be used as a basis of billing. For installations having over 100 hp, one minute will be allowed for every additional 100 hp, or fraction thereof, up to and including 500 hp. When the installed capacity exceeds 500 hp, a five-minute sustained peak will be used."

"When an integrating maximum demand meter is installed, the maximum demand for any month will be taken as the highest average demand for any ten consecutive minutes during the month."

"The demand shall be the highest average consumption measured in kilovolt-amperes during any consecutive five minutes within a given period."

"Where the demand charge is on a monthly basis, the maximum demand of electricity supplied in any month shall be the highest average number of kilowatts recorded in a single 30 minute interval in such month, but where the demand charge is on a yearly basis, the maximum demand for any one month shall be the highest average number of kilowatts recorded in three 30 minute intervals in such month, one interval to be selected from each of three different days."

The A.I.E.E. standardization rules say:—"The maximum demand of an installation or system is the greatest of all the demands which have occurred during a given period. It is determined by measurement, according to specifications, over a prescribed time interval." In accordance with specifications, a demand may be measured by an instrument with a time lag; or an instrument integrating the load over the prescribed time interval; or the load may be determined from a sufficient number of readings of an indicating instrument taken over the time interval. Thus the question of the time over which the peak load lasts, or the demand duration, is equally as important as its intensity.

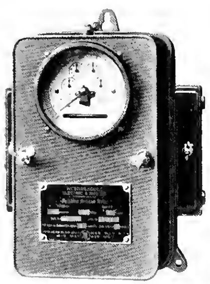


FIG. 1—POLYPHASE WATTHOUR AND MAXIMUM DEMAND METER

The use of an averaged maximum kilowatt demand computed from several demands read on different days manifestly tends to lower the maximum demand on which the charges are based. From the commercial point of view, the use of an average maximum demand may be very desirable, especially in the case of large consumers whose loads may be subject to occasional temporary increases from causes beyond their control. In the last analysis it is imperative that the basis of a demand charge shall be and shall appear equitable to the consumer.

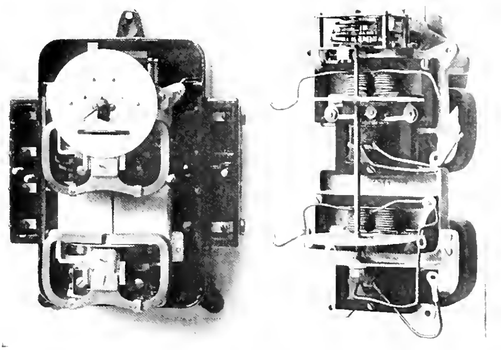
It is well known that the factors affecting the possible output of a generator are temperature and regulation, and that the temperature of a machine is a function not only of the load, but also of its duration, that is, of its load history. If a sudden excess demand comes upon the generators, similar to a short-circuit or ground, or a motor-starting load that lasts over a relatively short interval, then this sharp peak affects the generating and distributing capacities but little, and cannot be judged to constitute a maximum demand. The consumer should not pay excess for this, nor should the demand meter register it. The time of the duration of the load must be considered, and sudden excesses should be averaged or integrated over a considerable period, but just what this period or time interval should be has been the subject of much contention. Further extension of the use of the demand meters will doubtless cause this variable to be limited or fixed.

Recent developments in maximum demand meters have been along two distinct lines, differentiated only by the nature of their time elements:—

A—Those instruments whose deflection is retarded or purposely made sluggish, known as "Lagged Demand Meters."

B—Those instruments whose demand-recording mechanism is periodically reset to zero by a clock or equivalent time-keeping device, known as "Interval Demand Meters," or "Integrated Demand Meters."

A—Time Lagged Demand Meters, in measuring the maximum demand, require an appreciable interval of time to record the full value. This interval is usually from five to thirty minutes, depending upon the rapidity of load fluctuations, though often as low as one, two or three minutes where fluctuations are rapid. The meter integrates the load to the end of the time period, being then in equilibrium. Subsequent lighter loads will not show any registration, but subsequent greater loads will be integrated over the time period of the meter and cause higher registration than before. Unlike the time interval meters, these lagged demand instruments take cognizance of the previous load history.



FIGS. 2 and 3—MAXIMUM DEMAND METER
With cover removed and with electro-magnets and dial mechanism removed.

The time lagged meters will indicate approximately the same value of maximum demand on loads which are comparatively steady over the time interval of the instrument, but will not necessarily give the same results on fluctuating loads as the time interval meters.

B—Integrated or Time Interval Demand Meters are periodically reset to zero by a clock or timing device, and hence their action is to arbitrarily record the re-

curring blocks of power, and the integrated demand for each block. These time interval meters do not, on fluctuating loads, give exactly corresponding readings. If the excess load, for example, started at the middle of one of the time intervals of this latter type of meter, and lasted to the middle of the successive time interval, half would be recorded by the meter in each interval. On the

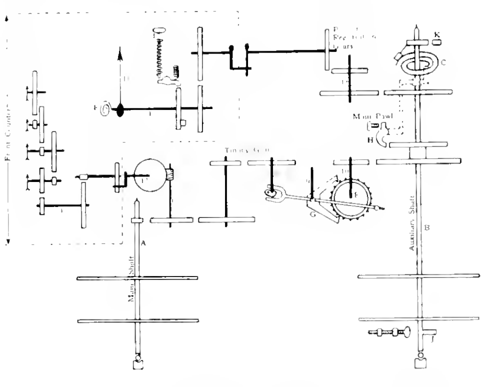


FIG. 4—SCHEMATIC DIAGRAM OF POLYPHASE DEMAND METER
Showing dial mechanism.

other hand, if the interval of the meter coincided with the time and duration of the excess load, obviously the meter would record the true integrated maximum at the end of its time interval,—a value twice as great as in the previous case. The answer to this criticism is that wherever conditions are such that the demand quite often repeats itself, the true maximum will, in the long run, be recorded by the "time interval" instrument.

In order to illustrate the action of demand meters of the *time lagged* class, a description follows of the Westinghouse Type RO demand meter.

This instrument has for its watthour element the usual shaft and disc of the integrating watthour meter (or the two-disc shaft, if polyphase) *A*, Fig. 4, and in addition an auxiliary shaft *B*, with discs rotating in the same air-gaps. There are the usual calibrating screws for moving the permanent magnets in or out to increase or decrease the speed, and the screws for moving the flux short-circuiting coils in the electro-magnetic air-gaps for speed changes for light load adjustments.

The auxiliary shaft, restrained in its forward (clockwise) movement by a spring *C*, will tend to immediately take up a position of equilibrium under load, its angular rotation being directly proportional to the energy flowing through the meter, as in the case of the well-known induction type instruments. The auxiliary shaft rotation, through shafts *11*, *13*, *3* and *1*, and through an indicating hand *D* sweeping over a large demand dial, would give an instantaneous reading of demand, except for the fact that the forward movement of this auxiliary mechanism is restricted by means of an escapement *E*, itself controlled by the watthour element through shafts *6*, *7*, *8* and *9*.

Rotation of shaft *A* causes the claw *G* to oscillate, allowing shaft *10*, the auxiliary shaft *B*, and the gear train up through shaft *1* to progress in steps actuated by the load torque on shaft *B*, and restrained by spring *C*. When the torque due to load balances the spring *C*, the escapement wheel *E* ceases to rotate, although claw *G* continues to oscillate as long as energy is passing through the meter. Watthour registration is secured on the four-dial counter through shafts *6*, *12*, *2*, *4*, etc.

At any time desired, the trip rod *I* may release shaft *1*, whereupon spring *F* returns pointer *D* to zero. When the load goes off, spring *C* returns shaft *B* to zero, against the adjustable stop *J*. If the main pawl *H* be raised, the rotation of shaft *B* will be directly transmitted to pointer *D*, independent of the escapement mechanism, and in this condition the strength of spring *C* may be adjusted by turning the pinion *K*.

Any time interval desired may be secured, and this interval, which is the time required after the change in load for the demand indicating mechanism to come to equilibrium, will repeat itself exactly. If, starting from zero, one load be twice the value of another, the demand pointer at the end of the interval will indicate twice as high on the scale. But also the watthour element (shaft *A*, etc.) during this interval will be rotating at twice the speed, hence operating the escapement twice as fast, and allowing the demand hand to progress at twice its previous rate, so that it will reach its maximum reading, or point of equilibrium, in the same length of time, regardless of the load.

Reference to Fig. 5 will make this more apparent. Assuming that the meter interval is 15 minutes, then if 5 on the demand scale represents full load, the point *A* represents the deflection of the demand pointer caused by constantly applied full load for 15 minutes. The line *OA* represents the deflection of the demand pointer, and from it the deflection at any intervening time may be de-

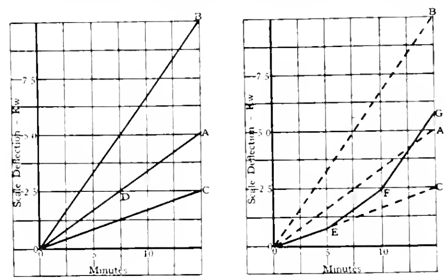


FIG. 5 FIG. 6

FIGS. 5 and 6—DEMAND CURVES
With constant loads (Fig. 5) and increasing loads (Fig. 6).

termined. At the end of 7.5 minutes the deflection would be at the point *D*, or a reading of 2.5 kw.

The definition states that an "integrated demand" for any load condition is equal to the total kilowatt-hours for the time interval, divided by the time in hours. In the above case the true integrated demand is re-

corded, because, according to definition, the integrated value would be for full load of 5 kw:—

$$\frac{5 \times \frac{15}{60}}{\frac{15}{60}} = 5, \text{ the reading at point } A.$$

Or for any other load, say 10 kw:—

$$\frac{10 \times \frac{15}{60}}{\frac{15}{60}} = 10, \text{ the reading at point } B.$$

Or for any other time interval, say 7.5 minutes at full load:—

$$\frac{5 \times \frac{7.5}{60}}{\frac{15}{60}} = 2.5, \text{ the reading at point } D.$$

If, for instance, the load on the same five kw, 15 minute meter be an increasing one, as follows:—2.5 kw for five minutes, followed by five kw for the next five minutes, in turn followed by ten kw for the final five minutes, then Fig. 6 will graphically illustrate the action. The demand pointer will advance as along line *OC* to the five-minute point *E*; then, the load being changed, it will advance along a line drawn from *E* parallel to a new rate-of-increase line *OA* to the ten-minute point *F*; and the load again changing, it will advance from *F* parallel to the new rate-of-increase line *OB* to the fifteen-minute point *G*, this being the final and true integrated demand reading, since,—

$$\frac{2.5 \times \frac{5}{60} + 5 \times \frac{5}{60} + 10 \times \frac{5}{60}}{\frac{15}{60}} = 5.83 \text{ kw.}$$

It is obvious that a time-lagged meter will not record a ten kw load as *10* on the demand dial unless the load lasts for the entire time-period of the instrument. If, on the three-minute interval meter, a demand load of, say 90 kw, lasts but 0.5 minutes, the integrated value (recorded on the large demand dial) would be

$$\frac{90 \times \frac{0.5}{60}}{\frac{3}{60}} = 15 \text{ kw,}$$

and it will not register 90 kw unless the duration of the load is for three minutes.

Characteristics of Fan Blades

O. S. Jennings

THE following article will be confined to a few of the best known and most commonly used fans of the propeller or disc type, i. e., those giving axial air flow. As every curve in the surface and edge means a different performance with different critical points and changes in air flow, it would otherwise be difficult to keep within the scope of an article of this sort.

DISC fans at first had flat triangular-shaped blades, were noisy and of rather light construction. As the fan business increased and their uses became more important, a general attempt was made to improve their efficiency. The first real effort in this direction seems to have been along those lines which had proved to be best in the design of marine propellers. This was a move in the right direction, and the standard blade of today is modeled after the marine propeller, i. e., has rounded tips, screw pitch and concave surface.

However, in addition to the development of blades of this type, many other freak fans sprang up, each putting into effect some particular idea of the inventor. The main effort seemed to have been to make sure that no movement of the air would take place radially, the blades being so shaped that only a flow in the direction of the axis could take place. Tests show, however, that there is little danger of a radial flow unless the angle of the blade is excessive. The least productive of results of any of these wide departures was the tandem arrangement of the blades. There is nothing gained by mounting one blade behind another, but the power expended is increased directly as the number of blades so mounted.

The best-known types of fans are shown in Figs. 1, 2 and 3; standard blades at *A*, *B* and *C*, blades with bent-over tips at *D* and *E*, and at *F* a blade intended to scoop air in at the center and throw it out axially at the tip.

SHAPE OF BLADE

As originally designed, the blades were flat with the widest part at the tip. Investigation early showed that very heavy eddies occur at this point because of its high velocity and abrupt ending. On account of this high velocity, both surfaces of the blade at this point are under suction, the air coming in radially, even ahead of the fan. It is quite natural then that heavy eddies should arise when the air is redirected to flow along the axis. To avoid this, it was apparent that the tip would have to be removed, but as this was impossible the blade was tapered off gradually instead of being allowed to end square. This was found to reduce the losses and diminish the noise made by the blade with a consequent rise in efficiency, true efficiency being considered as the energy in the air in the direction of the axis of rotation divided by the total energy imparted to it. However, the total volume of air per unit of power is found to be greater with the square-ended blade. This merely means that by rounding the tip the effective diameter of the fan has been decreased. The same thing is true of the marine propeller, viz., that a heavier thrust can be carried with square-ended blades on a smaller diameter

than with elliptical blades, although if a larger diameter elliptical-blade wheel could be swung the same thrust could be obtained with less power.

In addition to rounding the tips, it was found desirable to concave the blades slightly, as such a surface would tend to reduce the pulsations in the air by accelerating it more gradually. It also has the advantage of stiffening the blades and allowing the use of thinner metal with a reduction in the loss at the edges. The humming of the blade, however, is likely to be increased by greater stiffness of the blade. This is only true in those cases where the velocity of the blade is high enough to cause it to be set in vibration by the disturbance in the air.

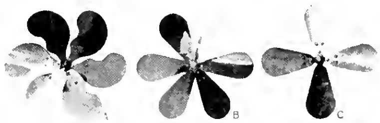


FIG. 1—TYPICAL VENTILATING FANS
A—Six-blade type of special shape with wide concave blades and unsymmetrical edges.
B—Six-blade type of approximately elliptical shape with standard screw pitch and concave surface.
C—Four-blade type, similar to *B*.

The curving of the blade is a point that needs a great deal of attention, otherwise a very inefficient fan may be obtained. If the curve is too great the acceleration at the trailing end may become so great as to cause the air to run into the entering edge of the succeeding blade. Such is the case with the blade shown in Fig. 4. This fan had been in operation in a place where the air was filled with fine sand, and the effect of the sand-blasting of the particles on the blade is shown by the shaded portion. It is obvious that the air was actually running into the back side of the fan blade at its entering edge, while on the front side the air did not touch the blade until near the trailing edge. The particles of sand were so fine as to be practically invisible, and hence the effect of their inertia can be neglected. A slight change in the curvature of this blade produced uniform action all over the surface.

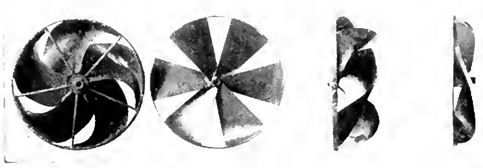


FIG. 2—TYPICAL EXHAUST FANS
D—Six flat blades with tips bent forward.
F—Five scoop blades with special tips.

The most important change, however, from a flat blade was the attempt to approximate a true screw pitch in the fan. This meant that as the blade receded from the center, the angle which it made with the plane of rotation had to diminish so that $2\pi r \tan \theta$ was a constant, where r is the distance from the center. Tests have shown that the true screw pitch raises the efficiency about 20 percent. It is, however, very difficult to make a blade of sheet metal with a true screw pitch and concave surface; consequently the majority of blades are only an approximation to the true surface.

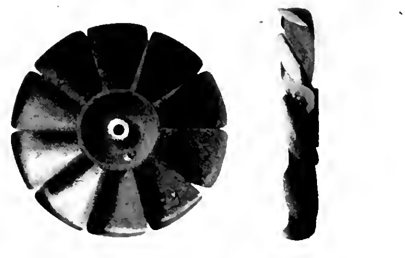


FIG. 3—TYPICAL EXHAUST FAN E
With large blade area, bent tips, approximate screw pitch and special curved surface.

For certain classes of service it is desirable to have the air moved spread itself out over as large an area as possible. To accomplish this numerous auxiliary devices to be attached in front of the fan have been devised, but the same result may be obtained by giving the blades a rake, that is, pitching them forward or backward, as the case may be, or by giving them a very heavy pitch to create a radial flow. A backward rake will tend to spread the air, while a forward rake will concentrate it. At one time most fans for free air delivery had a slight backward rake to the blade, but with the advent of the oscillating fan this feature was generally omitted.

In addition to the above changes in the design, numerous blades of an odd character have been brought out by inventors, such as the Blackman, Davidson, Ventura, Crynos, etc. Most of these peculiar blades were designed primarily for working against pressure and show such a form as will prevent a radial flow at the tip, making it impossible for the air to move off except in the direction of the axis.

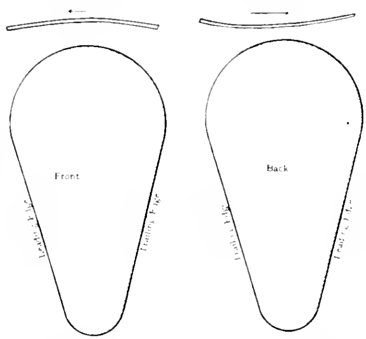


FIG. 4—EFFECT OF SAND IN AIR ON A FAN BLADE
Shaded portions show where there is air impact on the blades.

FAN CHARACTERISTICS

Preliminary to a consideration of fan characteristics it might be well to examine the manner in which the fan

blades cause the air to flow. It is commonly considered that the impact on the front of the blades is the cause of the movement of the air; but it is probably the suction or absence of pressure behind the blades which causes the air movement rather than any impact on the front side. Tests on the wings of aeroplanes have shown that the pressure below the wing is nearly that of the surrounding atmosphere, but that above the wing the air is highly rarified, and that it is this suction which draws the machine up rather than the impact on the lower side of the wing. It is quite likely that the fan blades act upon the air in the same manner, and that any blade which is best shaped to create a vacuum behind it will move the largest amount of air. It is, of course, very difficult to measure pressure before and behind a fan blade in rotation, but with the wings of an aeroplane this is easily done. Propellers for aeroplanes have been redesigned in accordance with the information thus obtained, and the result is an increase in propeller efficiency from 60 to 80 percent. It is possible that the fan and air propeller are not in the same class, since one is stationary and the other works at a low slip, traveling along as it turns. It, nevertheless, is probably true that the information used to such advantage on the aeroplane

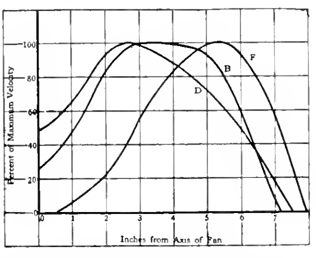


FIG. 5—VELOCITY OF AIR IN FRONT OF TYPICAL FAN BLADES
The letters on the curves correspond to the letters in Figs. 1, 2 and 3.

propeller might be applied to fan blades with equal success. It certainly would do away with most of the odd-shaped blades.

The actual velocity of the air in front of the blade has been measured, and is plotted in Fig. 5 for several types of fans. The letters on the curves are the same as those given to the fans in Figs. 1, 2 and 3. Curve *B* is for the standard type of fan used mostly for moving air in a room. It gives the most nearly constant velocity of any. The velocity decreases at the center and the tip, due to the fact that the true screw pitch is not carried all the way in toward the center and that the tips are rounded to prevent losses at this point. Curve *D* shows the distribution of the velocity delivered from a fan with bent-over tips, which has a strong tendency to concentrate the air toward the center, with a weak delivery at the tip. At *F* the delivery of an odd-shaped fan is shown where the air movement is almost wholly at the tip. In some respects this fan acts like the centrifugal type, taking the air from the center and throwing it out of the tip, but differs in that the air is thrown out axially instead of radially because of a peculiar curve at the end of the blade. As might be expected, this fan exhibits, when working against pressure, the characteristic of taking its air at the center from both before and behind the fan, a rather undesirable feature, as fans for exhaust purposes, such as this is used for, should take the air from behind the fan only.

BASIS FOR COMPARISON OF BLADES

The efficiency of a fan is a rather indefinite quantity as it may be taken as the cubic feet of air moved per minute for a given amount of power or the ratio of the amount of energy in the air moving along the axis to that expended. These two quantities are radically different, inasmuch as the cubic feet per watt depend largely on the velocity at which the air is moved. However, inasmuch as a fan is intended to move air, it would seem that such a basis would give the best means of comparison. If the fans are of the same diameter and the total number of cubic feet delivered is the same, it will also give some idea of the true efficiency of the blade. Consequently, this method of comparing fans will be used. The result will be called the effectiveness of the fan rather than its efficiency.

The general performance of the fan is mostly affected by the speed of rotation. At every change in angular velocity the power, volume of air delivered, effectiveness, noises and losses are altered; sometimes in a regular manner and at others very irregularly. Tests on aeroplane wings show that the air reactions are so erratic that no simple, if any, formulae can be used to represent them. The most definite relation is that between speed and power, the power varying as the cube of the angular velocity. This relation seems to hold from very slow rotation to speeds beyond the strength of most fans. Any variations from it are due rather to distortion in the blades than to any departure from the law. One would naturally expect the volume of air delivered to vary directly with the speed. Tests show that such is the case, but that it is not directly proportional to the speed. A certain definite number of revolutions, about 200, for a 12 inch fan, are required to get the regular delivery started; the higher the pitch the less this speed is. The volume does not follow a constant law to anything like the same extent that the power does. At very high speeds there will be a falling off in the amount of air moved, although with standard type blades, like those shown in Fig. 1 at *A*, *B* and *C*, such a departure will occur only at extremely high tip velocities. So far as the energy to deliver a given volume of air is concerned, the lower the velocity at which it is delivered the greater will be the effectiveness of the fan, as the energy per cubic foot will be much less. Thus the slower a fan runs the greater the effectiveness as defined. In designing fans, however, it must not be forgotten that a high velocity is necessary if the air is to be moved any great distance. The true efficiency of the fan, though, is very materially and differently affected by the speed at which it runs. It rises rapidly to a maximum at some given

speed and then diminishes as the speed is still further increased. A test made on a two-blade fan showed a true efficiency of 16 percent at 600 r.p.m., 44 percent at 1000, 75 percent at 1600, and 70 percent at 2000 r.p.m. Tests on three other fans showed the same general characteristics and indicate that for a given pitch and blade

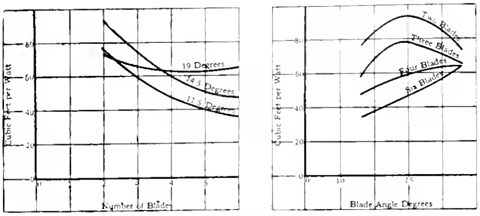


FIG. 6—RELATIVE EFFECT OF BLADE ANGLE AND NUMBER OF BLADES ON AIR OUTPUT

shape the maximum efficiency is developed at some given speed and that this speed is independent of the number of blades.

In addition to the speed, the pitch and number of blades have a very important bearing on the performance. By pitch is meant the amount of advance the surface would make if it moved in a solid medium as determined by the angle of the blade. Measurements on blades of constant angle show that the power varies nearly as the square of the sine of the angle, and the delivery as the tangent of the angle. At angles above 50 degrees there is considerable departure from this relation, especially in regard to the air delivered axially. It can readily be seen, then, that both the effectiveness and true efficiency of the blade will increase with the angle of the blade up to a certain point, which varies with the number of blades. Data obtained with two, three, four and six blade fans of the *B* type is given in Fig. 6. These curves show that at high angles a many-bladed fan is more effective than one with a small number of blades, but that at lower angles the opposite is very pronouncedly true. The effect of the number of blades is to lower the true efficiency at high speeds, but to raise it at low speeds. Tests made on a 16 inch fan blowing through a one-foot partition show the following efficiencies:—

At 400 r.p.m.	
Two blades	6 percent
Three blades	8 percent
Four blades	10 percent
Six blades	4 percent
At 1600 r.p.m.	
Two blades	75 percent
Three blades	68 percent
Four blades	54 percent
Six blades	43 percent

At speeds lower than 400 r.p.m. it is possible that a six-blade fan will show up better than a four. In general, a high-pitch fan with a moderate number of blades will give the best results. When considered from the standpoint of noise, this is all the more true, as the higher the pitch the slower the fan can be run for a given air delivery; also the greater the number of blades can be with a resultant lessening of the amplitude of the air pulsations.

Objects in the path of moving air, whether before or behind the fan, exert a considerable influence over its characteristics. An ordinary fan blowing 1000 cubic feet of air per minute in free air will, when placed in a thin partition, blow only 850 cubic feet per minute. An object held behind the fan will create considerable noise and cause a decrease in the air delivered, while one in front will effect the delivery only, the noise being about the same. The strangest effects are observed when a fan is placed in a tube. If the tube is placed in front of the fan, the volume of air will be very materially cut down, while if the tube is placed back of the fan there will be almost no effect at all over that in free air, the power remaining the same in both cases. This is true for almost any type of blade, although less so for blades with bent tips. The effect is without doubt due to a change in air flow at the blade tips. A number of curves are given in Fig. 7, which show the effect of a tube in front of the fan with different types of blades. These curves show that there is first a marked decrease in the air delivered, the decrease becoming less marked as the tube is increased in length. Undoubtedly the effect of the tube after the first two feet is that of increased pressure rather than of the flow through the blades. Curves *C* and *F* are for fans with very wide blades and indicate that a fan of this sort is most desirable for exhaust fan work, where the diameter is limited. It is to be noted in the same figure, however, that these fans are absorbing more power per cubic foot of air delivered than the others. If a fan of larger diameter with narrower blades had been used, the same volume of air would have been delivered through the longer tube, with more air through the shorter tube for the same cubic feet per watt.

A fan working against pressure exhibits many peculiarities. If the blades are few in number and narrow there will be an almost uniform decrease in the volume of air delivered with an increase in the pressure. As the number or width of the blades is increased, the fan is

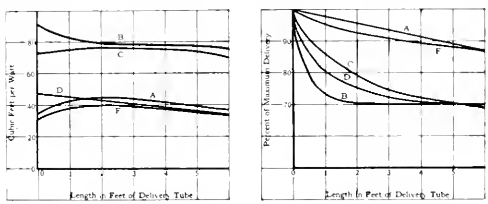


FIG. 7—EFFECT OF DELIVERY TUBE ON AIR OUTPUT
Tests made with a 12 inch fan in a 13.5 inch tube.

better able to maintain its delivery. In all cases, however, there is a rapid fall at first, but if the number of blades or the width of the blades is large this is followed by a period of constant delivery with increasing pressure, a point finally being reached where the fan will not deliver any air.

The actual delivery of the air from the fan has many interesting characteristics. With the standard form of blade, such as *A, B* and *C*, it is first along the axis and then at an angle to the axis. The greater the pressure the greater this angle becomes. At the point where the fan ceases to blow air inwardly the flow is almost

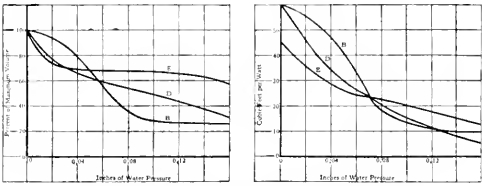


FIG. 8—EFFECT OF PRESSURE ON VOLUME OF AIR
Constant speed with power identical at zero pressure for all fans.

radial. In other words, the effect of pressure is to produce a radial flow instead of an axial flow. Any disc fan working against pressure has a return flow at the center, a sort of huge eddy. In no case does the air pass through the blades to the back side, but flows radially to the tips, where it is again thrown out axially. The effect of pressure on the power is to cause an increase, usually steady, but sometimes erratic, although there is a tendency at first for the power to be decreased very slightly.

Figs. 8 and 9 show the delivery of three types of fans against pressure. Curves *E* and *D* show the performance of fans especially designed for working against pressure, while curve *B* covers a standard blade fan. It should be noted that the special types of fans at low pressures when running at constant speed are much poorer than the standard type, and at high pressures not any better. In Fig. 9 the effectiveness curves have been plotted for the delivery of a constant volume with a given diameter of blade, the speed being varied to effect this condition. They show the same general characteristics as in Fig. 8, where the speed was constant and such as to make the power for all the fans the same against zero pressure. In Fig. 8, *E* is a ten-blade fan, and probably owes its superiority at this pressure to this fact rather than to its blade shape. If fan *B* had as many blades it would probably make a better showing against pressure than any of those tested, for curve *D* is that of the same type as *E*, but with six blades, the same as B. At light pressures *B* is far superior to the others.

CONCLUSION

Although only some of the most important points in the performance of fans have been treated, it will be apparent to one familiar with the subject that the disc fan art is very far from being in a high state of development. All sorts of fans are in use for which various claims are made which the users cannot verify, and many of which are of doubtful accuracy. The basis for many erroneous claims is undoubtedly the result of poor testing, both because of wrong methods and because of difficulties in making measurements. As the users cannot verify these claims, the manufacturers have not been compelled to improve their product. It is also apparent that by comparing fans of different diameters or of the same diameter, but running at different speeds, one fan or another may be made to show the best results. In fact, it might be said that any fan can be shown to be superior to another if only they are compared with this end in view. Both the test data shown here and other data indicate that the fan blade of the future will undergo some marked changes, the most important of which will be the disappearance of the freak blade. New curves in the blade surface, shapes of the tip and width and number of blades will add greatly to the efficiency and effectiveness of fans. There will probably be two types, one for free air work and one for exhaust fan work. Accurate and careful test methods, as well as measurements, will be essential before definite results can be obtained, since fan blades will be designed from the results of tests rather than calculation for some time to come. Until someone investigates the flow of air around

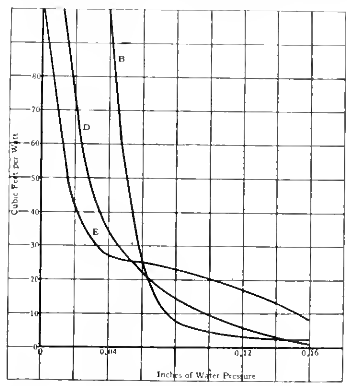


FIG. 9—EFFECT OF PRESSURE ON VOLUME OF AIR
Volume constant at all pressures with speed adjusted to give necessary pressure.

and over the blade surfaces, the distribution of pressure, and the formation and meaning of eddies, there is little probability of the determination of any mathematical formulae that will give the performance of a disc fan under all conditions.

Testing Large Oil Circuit Breakers

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THE magnitude of large alternating-current power systems, with their continually increasing k.v.a. ratings, higher distributing voltages and consequent larger amounts of power concentrated at short-circuits, makes the certain operation of large capacity oil circuit breakers of great importance. A careful analysis of the possible short-circuit k.v.a., taking into consideration the reactances of all synchronous apparatus connected to the lines, as well as the reactance, resistance and capacitance of the transmission lines, is essential in order to insure the selection of circuit breakers having suitable characteristics. Circuit breakers for such large power service must be most carefully and substantially proportioned in order to interrupt the enormous currents at high voltages which flow at such times.

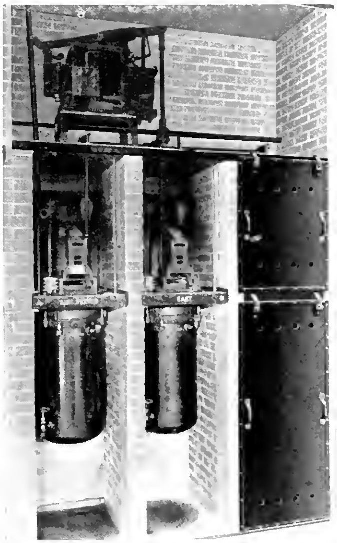
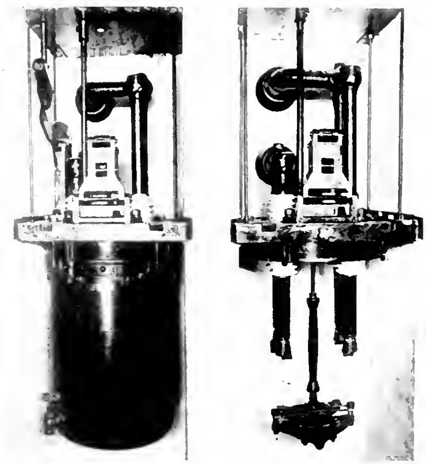


FIG. 1—THREE-POLE, 25 000 VOLT, 1200 AMPERE, TYPE O-1, ELECTRICALLY-OPERATED OIL CIRCUIT BREAKER

In order to provide a check on the actual performance of such an oil circuit breaker application, under actual service conditions, a series of tests was made recently on a circuit breaker of the type shown in Fig. 1, in which were successfully interrupted short-circuits having a peak value of 950 000 k.v.a. and root-mean square value of 475 000 k.v.a. at the time the contacts opened, both symmetrical values, at 24 500 volts, representing the largest amount of power which has ever been used for such a test. The unsymmetrical peak value of the initial wave of this short-circuit was 50 percent greater, representing 1 425 000 k.v.a. The circuit breaker, as shown in Fig. 1, was of the separate mounting type for mounting apart from the control switchboard and for remote control electrical operation. It was designed for opening the heaviest possible short-circuits on systems up to 25 000 volts, the maximum normal load current rating being 4000 amperes.

These circuit breakers are composed of single-pole units, each unit being mounted in a separate brick or concrete compartment, as illustrated in Figs. 1 and 4. The mechanism is solenoid operated and consists of a common operating shaft, with levers and rods operating the several poles as a unit. Each pole unit is complete with a heavy steel frame supporting the contacts and tanks and provided with an independently adjusted toggle lever arrangement for operating the moving contacts. The adjustments for contact pressure and travel can be made in each pole unit independently. An accelerating spring and dashpot device is operated as part of the common control mechanism to assist in forcing the circuit breaker to the open position and in taking up the shock of the moving parts. The terminal studs and stationary contacts are supported by vertical terminal stud insulator bushings clamped to the steel frame of each pole. Lock washers are used on the clamp bolts and conducting details to prevent loosening from the vibration incident to the rapid operation of the circuit breaker.



FIGS. 2 and 3—DETAIL VIEWS OF ONE POLE OF CIRCUIT BREAKER SHOWN IN FIG. 4

The contacts open by gravity, thereby tending to open the circuit in case of any accident to the operating mechanism. All contact pressure reacts vertically downward to assist gravity in the opening operation. The main moving contact member consists of a laminated copper brush or bridge forming an "end-on-high-pressure," self-cleaning contact with the stationary contact surfaces on the terminal bushing studs. The main contacts are shunted by heavy arcing contacts of the butt type, which open after the main contacts and protect them from the action of the arc in breaking the circuit. The live metal parts of each pole are immersed in a separate single piece round steel tank which can be removed readily without interfering with the other parts of the circuit breaker. Drain and filler fittings and oil gauges are supplied so that the tanks can be emptied before lowering, or filled when in position. As a protection from arcing to ground, a removable micarta insulating lining is used in each tank. The tanks are deep to allow ample head of oil and space above the oil for a compression chamber to reduce internal gas pressures.

The standard circuit breakers of this type are provided with direct-current control trip coils in addition to the direct-current control closing coil. For this test the breaker was made automatic by means of current

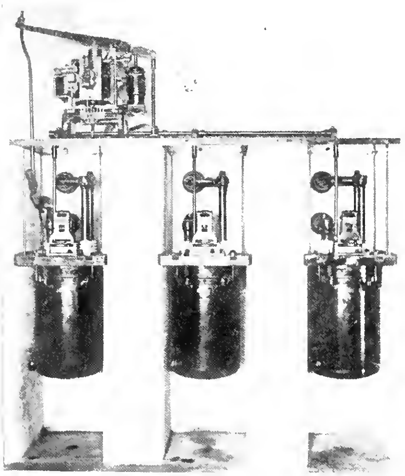


FIG. 4—THREE-POLE, 25 000 VOLT, 2000 AMPERE, TYPE O-2, ELECTRICALLY-OPERATED OIL CIRCUIT BREAKER

transformers and instantaneous relays controlling the direct-current trip coil.

DESCRIPTION OF TESTS

A circuit breaker of the type shown in Fig. 1 was arranged to open the circuit of a 24 500 volt short-circuit with a total connected capacity in 60 cycle synchronous generating apparatus of 142 620 k.v.a.* The generator voltage was stepped up through a total transformer capacity of 90 500 k.v.a., and oscillograph records were made of each test. The oscillogram showing the severest conditions is reproduced in Fig. 5. Under the conditions of the test, it was possible to obtain current readings of only two of the phases and a reading of the voltage in one phase. The record shows that the short-circuit continued for six cycles on a 60 cycle circuit

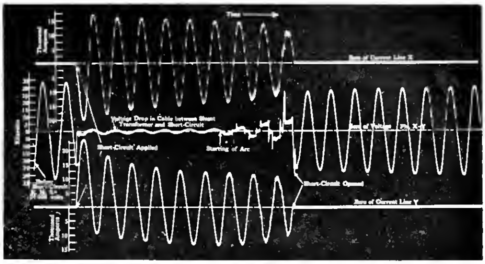


FIG. 5—OSCILLOGRAM OF 24 500 VOLT, THREE-PHASE, SHORT-CIRCUIT TEST

On a 25 000 volt, 500 ampere, type O-1 circuit breaker, interrupting a direct short-circuit on 142 620 k.v.a. of synchronous apparatus, representing the most severe short-circuit ever opened on test. The current and voltage waves were traced from the oscillogram separately for greater legibility.

before the circuit breaker contacts parted and continued for three cycles through the arc. This short-circuit, as well as the previous ones, was opened by the circuit breaker without difficulty, the same arcing contacts and oil being used in all the tests. The only external effect was a small amount of oil forced out through a defective joint between the tanks and frame.

At the time the circuit breaker contacts operated, phase X had a maximum current of approximately 16 000 amperes and phase Y a maximum current of 13 500 amperes, both of which are symmetrical maximum values, as shown in Fig. 5. This gives a root-mean square symmetrical current value for phase X of approximately 11 300 amperes which was ruptured by the particular pole unit. This when multiplied by $\sqrt{3}$ for the three-pole units and 24 500 volts gives a root-mean square short-circuit of approximately 475 000 k.v.a. and a maximum short-circuit k.v.a. as computed from the peak value of current and voltage waves of double the root-mean-square value, or 950 000 k.v.a. Fig. 5 shows that both current waves were symmetrical at the time the contacts opened, but were somewhat unsymmetrical on the initial wave of short-circuit, due no doubt to the varying amount of reactances between the generators and the short-circuit. The maximum current in the first half cycle of phase Y was approximately 24 000 amperes and in phase X 20 000 amperes.

There was no damage to the circuit breaker other than slight burning of the contacts and tank lining, which did not affect its continued successive operation.

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*See articles by Mr. J. B. MacNeill in the JOURNAL for Aug., '16, p. 364, and Nov., '16, p. 547; and by Mr. J. N. Mahoney, Apr., '14, p. 200, and Nov., '13, p. 1103.

The Mountings and Maintenance of Car Resistors

GENERAL ARRANGEMENT

While there are numerous satisfactory methods of installing car resistors, there are cases where the method of mounting is responsible for many car "pull-ins." To insure satisfactory operation, grid resistors should be kept as clean as possible, and protected from flying stones or wheel-wash by "wheel-wash" guards. Figs. 2 and 3 show recommended methods of installing car resistors for 600 and 1200/1500 volts, respectively. Whenever possible, grid resistors should be mounted near the center of the car, away from the splash as much as possible, and arranged so that they will get fairly good ventilation.

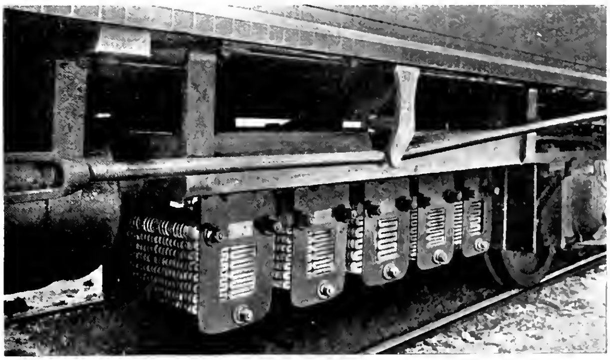

FIG. 1—GRID RESISTOR INSTALLATION ON AN INTERURBAN CAR

TIMBER MOUNTING BEAMS

This arrangement makes use of treated timber beams, resulting in comparatively large creepage distances between the individual frames and between the end frames and grounded hangers. The beams should be covered with asbestos lumber, or other fire-resisting and heat-insulating material, to prevent charring or ignition of the wood in case of overheating of the grids.

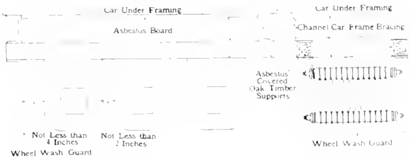

FIG. 2—METHOD OF MOUNTING GRID RESISTORS FOR 600 VOLT SERVICE

The method of supporting the beams depends primarily upon the layout of the car underframing. It may be desirable to support the beams in the center as well as at the ends.

HANGING GRID FRAMES

One method of hanging the grid resistor frames on the wooden beams is to use square-headed machine bolts. The beams are drilled and countersunk so that when the bolts are in place the heads will be about one-half inch below the surface of the beam. Insulating compound may then be heated and poured over the bolt heads, insulating them completely and keeping out foreign matter.

FIRE UNDERWRITERS REQUIREMENTS

To meet the fire underwriters' requirements, "where the underside of the car body is wholly or partially composed of combustible material, a protection of approved fire-resisting and heat-insulating material at least one-fourth inch in thickness must be installed directly above the resistors and extend to the edge of the car, or not less than eight inches beyond all edges of the resistor." Furthermore, "the insulation of the resistor cables must be removed for at least six inches back from the resistor terminals and the bare stranded wire must be filled with solder to make it rigid."

WIRING

The general scheme used is to bring the leads over the top of the heat-insulating barrier; then down through to the resistor terminals. This arrangement is illustrated in Fig. 1,

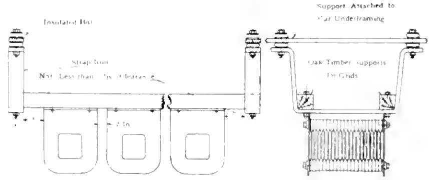

FIG. 3—METHOD OF INSTALLING GRID RESISTORS FOR 1200 AND 1500 VOLT SERVICE

which shows an application of grid resistors on an interurban car.

INSPECTION AND OVERHAUL

At times of heavy inspection and at light inspections, just after a new installation has been made, the terminals should be gone over to see that all cable joints are tight, and the through bolts should be tightened to take care of any shrinkage in the insulation, or any possible stretching of the tie bolts themselves.

Testing Polarity of Field Coils

OBJECT

The object of this test is to determine whether the main and commutating-pole field coils are properly connected. This test should be made whenever field coils are replaced, because coils are sometimes placed over the poles of the frame inverted or reversed, and wrong connections thus made show up in faulty operation of the motor. This test will show up conditions which might cause an armature to run hot due to an unbalanced magnetic field circuit caused by a reversed main field coil. It will also indicate conditions which might cause poor commutation and flashing in a commutating-pole motor because of a reversed commutating coil.

APPARATUS

The following apparatus is required:—A polarity detector, such as a small compass, a switch and several car heaters or sets of grid resistors. A circuit is arranged as shown in Figs. 1 and 2. At least five or six sets of heaters or frames of resistors should be put in the circuit at first. If a readable deflection on the polarity indicator is not obtained, part of the grids can be omitted. If one is available, an ammeter in the circuit will indicate whether the current is large enough to be liable to cause damage.

A very satisfactory polarity indicator can be made from a piece of steel banding wire about three inches long, with one end bent over about one-quarter of an inch to distinguish it. This is suspended at the middle by a short thread. When this is first used it should be held at the pole for at least one minute, when it will become magnetized, and is then ready for use.

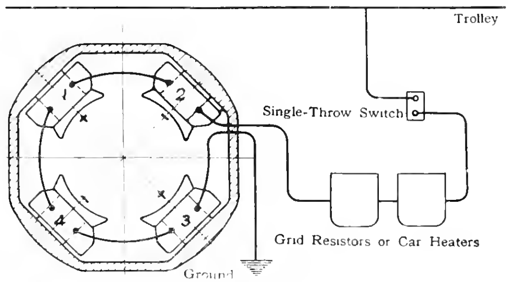

FIG. 1—CONNECTIONS FOR TEST ON MAIN COILS

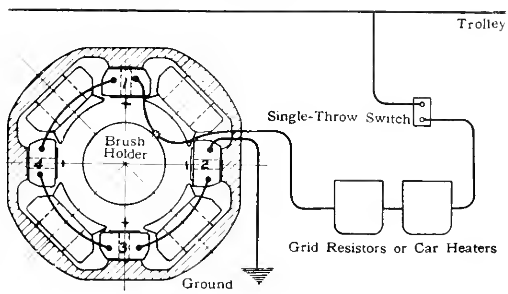

FIG. 2—CONNECTIONS FOR TEST ON COMMUTATING-POLE COILS

METHOD

The motor can be either on the trucks or out on the floor. It can have the armature in or out of the frame and, if a split frame, can be open or closed. With the coils all connected in series, connect the two field leads to the test circuit, as shown in Fig. 1. When the switch is closed, current passes through the field coils, and if they are connected properly, by holding the polarity indicator close to the ends of the coil, or to the pole stud bolts on the outside of the frame, the polarity indicator will reverse at alternate poles; i. e., if *No. 1* pole attracts the positive end of the polarity indicator, *No. 2* should attract the negative end, *No. 3* the positive end and *No. 4* the negative end. If these conditions are not obtained the field winding connections should be changed.

If the frame tested has commutating poles, two separate tests should be made, one on the main field coils as previously described, and the other on the commutating-pole coils, which is made in the same manner, with connections as shown in Fig. 2. In this case only one of the motor leads (the negative armature lead) can be used, as the other lead from the commutating coils goes to one of the brushholders. Four-pole railway motors with only two commutating coils, which are located directly opposite each other, also four-pole motors with three commutating coils, are tested in the same manner. In the case of the two-pole machine the polarity of both coils should be the same, while in the three-pole machine the two coils on diametrically opposite poles should be of the same polarity, while the intervening coil should have the opposite polarity.

PRECAUTIONS

In making this test.—

1—Hold the pivoted compass in a horizontal position; or the suspended polarity indicator by the free end of the suspension thread.

2—Test for polarity at the same end of all coils,—either the commutator or the pinion end, whichever is more convenient.

3—Never consider results final until they have been checked the second time, as there is a possibility of the needle of the indicator having its polarity reversed.

4—It is not necessary that a certain pole have a definite polarity of either + or —, but it is essential that the polarity of adjacent poles shall be different.

RELATION OF COMMUTATING-POLE TO MAIN-POLE POLARITY

In the case of a commutating-pole machine, it is important to have the proper relation of polarity between the main and commutating field poles. To check this connect the negative (—) armature lead of the motor to the positive (+) field lead, the positive (+) armature lead to the trolley side of the test circuit, and the negative (—) field lead to the ground side of the test circuit, and close the switch. If the armature is in the frame and the brushes are making contact on the commutator, current will flow through all the windings; if the armature is not in the frame, then it will be necessary to short-circuit the brushholders. With these conditions, the polarity of a main pole should be the same as the polarity of the commutating-pole next to it in a clockwise direction when facing the commutator end of the motor.

ENGINEERING NOTES

Conducted by R. H. WILLARD

Aim—To connect theory and practice

Dampers on Alternators

In single-phase alternators the armature reaction is pulsating. Fig. 1 shows a single-phase, two-pole alternator at the position of zero voltage between taps. This will occur when the tap coil is under the middle of a pole, because at that time half the coils between taps are under a north pole and half are under a south pole. Since these coils are in series their voltages neutralize so that there is no resultant voltage between taps. Assuming a load of unity power-factor, the current will be in phase with the voltage so that it and the armature reaction due to it will be zero in Fig. 1. Fig. 2 represents the conditions one-eighth cycle later, since in a two-pole machine one cycle corresponds to one complete revolution and one-eighth cycle corresponds to 45 degrees. In this position the coils from tap *B* to coil *A* neutralize each other, since half of them are under a north pole and half under a south, but from *A* to *C* the voltages add so that there is a voltage between *B* and *C* and a current will flow as indicated. The current flowing out on side *A* and in on the other side of the armature will magnetize it in the direction of the arrow. An eighth of a cycle later, conditions are represented by Fig. 3. Here all the coils *BAC* are under a south pole, generating voltages which tend to force current around the armature from *B* to *C*, in a clockwise direction. The coils under the north pole will tend to force current counter clockwise around the armature, i. e., *BDC*. Both sets of coils tend to make *C* the positive tap, so current will flow as shown where dots represent current coming out of a wire and crosses represent current going in. As before, the armature will be magnetized, but this time more strongly, since the voltage and current are a maximum, and in a different direction, since the magnetic axis of the winding has turned 45 degrees with the rotor.

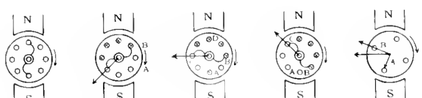

Fig 1 Fig 2 Fig 3 Fig 4 Fig 5

FIG. 6—TYPICAL DAMPER WINDING

Conditions one-eighth cycle later are shown in Fig. 4, and are practically the same as in Fig. 2. One-eighth cycle later, i. e., after one-half revolution, the tap coils are again under the pole centers and the voltage and current have again become zero. This completes half a cycle. As the armature moves further the direction of current in the coils is reversed, but since the coils have also moved half-way round the previous diagrams may be applied by interchanging *A* and *D*, *B* and *C*. It will be seen that the armature reaction varies from zero to a maximum twice during a cycle, but does not reverse in sign.

In the position of Fig 2 the armature reaction has a component which boosts the main field, and another which distorts the main field, tending to crowd it toward one side; in Fig. 3 it neither boosts nor bucks, but has a maximum distorting effect; in Fig. 4 it bucks the main field, and also tends to distort it in the same direction as in Fig. 2. This varying armature reaction causes a pulsation in the main flux through the field, which becomes severe in some cases and causes excessive heating of the field core due to iron loss. To obviate this trouble it is customary to supply single-phase generators with heavy damper windings. As the flux pulsates through these windings e.m.f.'s are induced, which circulate currents in the dampers, whose action is to neutralize the pulsation. The action is like a transformer where the armature corresponds to the transformer primary and the dampers to the secondary. Just as the core flux in a transformer depends on the exciting current which is not dependent on the total primary current, so the pulsating armature flux does not increase in proportion to the load current, but is kept nearly constant at a small value by the neutralizing action of the dampers which correspond to the transformer secondary.

Dampers are not necessary on polyphase alternators to overcome pulsating armature reaction. In Fig. 5 is shown a two-phase machine; the tap coils of one phase are at *A*, those of the other phase at *B*. The armature reaction due to the current in phase *A* is shown by arrow *A*; that due to phase *B* is shown by arrow *B*. The resultant armature reaction due to both phases is the vector sum of *A* and *B*, which are at right angles. If other positions of the armature are chosen it will be found that the sum of the reactions *A* and *B* is always the same in size and direction. In other words, the armature reaction ot a two-phase generator is constant in direction and magnitude. The same is true of other polyphase machines.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1393—Transformer Connections—We have a small central station of about 700 kw total capacity at three-phase, 3100 volts, 50 cycles. About one-third of the transformers used are three-phase, delta-connected primaries and Y-connected secondaries, and the other two-thirds are Y-connected, both primaries and secondaries. The three 225 kw generators are Y-connected, but the neutral i not used. Neither generators nor transformers are grounded. We have had troubles with burnouts of transformers, especially the old Y-connected ones. Please advise how this can be best remedied. In another station we have Y-connected generators, 4000/2300 volts, using mostly single-phase transformers between the neutral and phase wires, with the neutral grounded at the station, and we also have troubles when anything happens to the neutral which reaches each transformer. What will be the most satisfactory solution? E. D. (MEXICO)

The three-phase transformer that is connected delta primary and star secondary should operate successfully providing it is not connected in parallel on the secondary side with the star-star connected units. If the star-star connected transformers supply an independent line from the one supplied by the delta-star connected units, then they should operate successfully without their primary neutrals connected to the neutrals of the generators, providing the load, whether three-phase or three single phase, is connected to the phase lines; the neutrals not being used. If unbalanced single-phase loads are connected between phase lines and secondary neutrals, the star-star connected banks will not operate successfully unless the primary neutrals are connected to the neutrals of the generators. Assume that a single-phase load is connected between one phase line and the secondary neutral, and that the other two phases are not loaded, then the current for the load will flow through the neutral line, through the secondary of one phase of the transformer and through the phase line connected to the loaded phase of the transformer. A load of this kind draws current from only one secondary of the transformer. A corresponding current must flow in the primary winding of the loaded phase. But when the primary is star connected and its neutral is not connected to the neutral of the generator, then the current for the loaded phase must pass through one or both of the other phases. This results in drawing the load current through the high impedance of the unloaded phases, which results in developing a voltage across the unloaded phases. The same results are produced when the three phases are unequally loaded by connecting single-phase loads of different values between phase lines and neutrals. The voltages induced in the phases due to unbalanced loads are in addition to the impressed voltages. The resultant voltage produces extra voltage stresses on the insulation and may produce a high iron loss which may increase the temperature of the transformer. If the primary neutrals of the star-star connected transformers are connected to the neutrals of the generators the transformers should operate satisfactorily, providing they are of good design. J. F. P.

1394—Non-Condensing Turbine—Is it safe to run a steam turbine without vacuum on at full load, even if the steam pressure will hold up? E. M. D. (WASH.)

Any condensing type steam turbine or steam engine should operate safely non-condensing at any loads it is capable of carrying with a normal steam pressure. The deterioration of the machine might be somewhat more rapid, but there should be no immediate damage if the machine is in good condition. On account of the many designs of steam turbines on the market, the advice of the builders should, of course, be obtained on such questions. J. F. J.

1395—Parsons Type Turbine—In the Parsons or reaction type of turbine, what in general is the relation between the steam velocity and the blade velocity? L. E. B. (MICH.)

The present average velocity ratio, or ratio of blade velocity to steam velocity, is approximately 0.60 to 0.65 for small turbines and from 0.65 to 0.75 for very large turbines. Velocity ratios of up to 0.81 have been employed in one or two cases. The choice of velocity ratio depends upon the economy which it is desired to obtain—the better the economy desired, the higher velocity ratio required. There are other factors, however, which govern or limit the choice for any given rating and steam conditions, namely, cost of construction, difficulties in mechanical design, space occupied, weight, etc. Except in geared turbines, the velocity ratio in marine work is generally 0.47 to 0.52, though in a few instances a ratio of 0.57 to 0.58 has been used. In geared marine turbines the velocity ratios are about the same as in electrical work, though in naval vessels the velocity ratio at full power may be very much higher than in electrical work, the object being to obtain good economy at cruising speeds when the revolutions of the turbine are reduced. H. F. S.

1396 — Auto-Transformer — Will you please show in detail how the following problem can be solved? A 15 k.v.a., 1100/110 volts transformer is connected as an auto-transformer to step up from 1100 to 1210 volts. What will be the amount of power that can be delivered to a non-inductive receiving circuit at 1210 volts without exceeding the rating of the transformer? What will be the current in each coil of the transformer and the amount of power delivered? How would it be in the case the same transformer is used for stepping down from 1100 to 900 volts? J. M. deA. (NEW YORK)

Let e_1 and c_1 be the voltage and current of one section of the winding, and e_2 and c_2 the voltage and current of the other section, as shown in Fig. 1396(a). Then the line voltages will be e_1 on the low-voltage side and $e_1 + e_2$ on the high-voltage side, and the line currents will be c_1 and c_2 on the low-voltage side and c_2 on the high-voltage side. The current will flow as indicated by the arrows. Since the k.v.a. output is equal to the k.v.a. input (neglecting losses and magnetizing current), we have,—

$e_1(c_1 + c_2) = (e_1 + e_2)c_2$..................(1)

or $e_1c_1 + e_1c_2 = e_1c_2 + e_2c_2$,

or $e_1c_1 = e_2c_2$...(2)

Now suppose the two sections of the winding are separated so as to give a two-winding transformer, as shown in

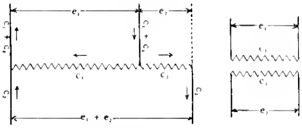

FIG. 1396 (a) and (b)

Fig. 1396(b). Then, since k.v.a. output must equal k.v.a. input, we have $e_1c_1 = e_2c_2$, which is the same as equation (2). Now in the case of the auto-transformer, the k.v.a. input is $(e_1 + e_2)c_2$, while in the case of the two-winding transformer the output is e_2c_2, and the ratio of these two outputs is,—

$$R = \frac{(e_1 + e_2)c_2}{e_2c_2} = \frac{e_1 + e_2}{e_2} \text{..........(3)}$$

Applying this to the specific example in the question we have $e_1 = 1100$ volts and $e_2 = 110$ volts. Then $R = \frac{1100 + 110}{110} = 11$. Therefore, if the output as a two-winding transformer is 15 k.v.a. the output as an auto-transformer, to give the same losses, is $11 \times 15 = 165$ k.v.a. When connected as an auto-transformer, the ratio of voltages on the two sides of the transformer will always be

$$\frac{e_1 + e_2}{e_1} = \frac{1100 + 110}{1100} = \frac{1210}{1100} = \frac{11}{10}$$

and therefore if the high voltage is 1100 the low voltage must be 1000,—it cannot be 900. The current capacities of the windings does not change, so that if the voltage is reduced the k.v.a. output is reduced in proportion. W. M. M.

1397—Direction of Rotation—In changing the direction of rotation of a wound rotor induction motor do you have to change the leads on the rotor as well as the stator? E. M. D. (WASH.)

No. It is not necessary to change the rotor leads for the reason that the stator determines the direction of the rotating magnetic field and the rotor winding simply acts as a generator and follows the direction of rotation of the magnetic field. The fact that the so-called "phase rotation" in the rotor winding is changed is of no consequence, since the collector rings are usually connected only to a resistance and not to other apparatus which would be affected by the direction of the rotating field. A. M. D.

1398—Mazda C Lamps—In the article on "The Development and Use of the Mazda C Lamp," by Mr. W. A. McKay, in the JOURNAL for June, 1916, mention is made of artificial daylight units employing Mazda C lamps. Please answer the two following questions regarding these units:—(a) Is the artificial daylight spectrum provided in the glass of the lamp itself, or is some special enclosing globe required? If the latter, what commercial product of glass is best suited? (b) Have such units been used commercially for blue-printing work? Is there any data available on the intensity of artificial illumination with such units necessary to print at a speed equal to bright sunlight? G. O. W (CALIF.)

(a) The artificial daylight units referred to make use of clear bulb Mazda C lamps, the desired spectral quality being obtained by causing the light from the lamp to pass through a glass plate having proper transmission characteristics. The unit as ordinarily used consists of an opaque reflector, frequently of white enameled steel, by means of which the desired light distribution is obtained, and a filter of bluish glass which is mounted in the opening of the reflector. Although it is comparatively simple to produce on a white surface, by means of screens of bluish gelatine or glass, light which seems to the eye the same as daylight, such light will not do for accurate color matching, etc., as when analyzed it is usually found to differ greatly from daylight in composition. The filter must therefore be very carefully designed in order that the spectrum of the modified light may be continuous and similar to that of North sky light, which is generally used as the standard light for color matching. (b) So far as we know, no data has been published on the illumination necessary for blue-printing with Mazda C lamps, but such lamps are not recommended for this work, as it would require a large expenditure of energy to make prints in a short time. W. A. M'K.

1399 — O.I.S.C. Transformer Rating Without Oil—I would like to be informed what percentage of rated capacity of oil-insulated, self-cooled transformers can be carried by the transformers without oil. The transformers in question are rated at 2200/220 and 440/110 volts, 25 and 60 cycle. It appears in these low-voltage transformers that the insulating quality of the oil might be overlooked and that the transformers might be used on reduced capacity. W. T. B.

Oil-insulated transformers are not designed to operate at all without oil. Power transformers are designed for low total loss at full load and not for low iron loss, as is the case for a lighting transformer. On 60 cycle power transformers the iron loss is approximately half the total full-load loss, and such transformers without oil would not stand continuously the iron loss without overheating, so that putting on any load at all for any length of time would be out of the question. Lighting transformers and 25 cycle power transformers would fare a little better in this respect, since the iron loss is a smaller percent of the total full load losses, but the amount of load that they could safely carry would be so small that it would not be an economical proposition. As a general proposition it would not be safe for any oil-insulated transformer to be excited at normal voltage continuously without oil even at no load. C. S. L.

1400—Rewinding an Induction Motor—We have a three-phase, 200 volt, 60 cycle, squirrel-cage motor wound as follows:—The coils lie in slots Nos. *1* and *12*, one complete coil per slot, two coils in series per group, eighteen groups total, connected two parallel star. The wire is No. 15, 56 wires per coil, two wires in parallel. Will this motor operate using the following winding, phase, voltage and frequency remaining the same? The coils lie in slots Nos. *1* and *9*, two coils per slot, four coils in series per group, eighteen groups total, connected two parallel star. The wire is No. 15, 28 wires per coil, two wires in parallel. The reason for wanting to use a throw of *1* and *9* is to use the same amount of wire in two coils as originally in one. If I must give the coils a throw of *1* and *13*, shall I reduce the number of wires per coil? If so, how much? H. W. W. (ORE.)

It is customary in changing a one-coil-per-slot winding to a two-coil-per-slot winding to maintain the number of conductors per slot and the throw of the coils the same, as well as the size of the conductor. It is not always possible to keep the number and size of conductors the same, because there is more space in the slot taken up by the insulation which is necessarily introduced between the two coils in the slot, but there is no reason for changing the throw of the coils. The two-coil-per-slot winding outlined above with *1* to *9* throw will probably operate satisfactorily, but the iron will be worked at a higher density, meaning lower power-factor, higher torque and possible lower efficiency. The performance that is obtained on the one-coil-per-slot winding will be more nearly duplicated if the throw is kept *1* and *12*. B. B. R.

1401 — Testing Magneto — (a) Please suggest both laboratory and road test methods of making comparative tests on high-tension magnetos. (b) How much condenser capacity would be required in series with a 110 volt, 60 watt lamp to have it burn at normal candle-power? (c) Please show by example how capacity is calculated. (d) Please explain fully the purpose of the condenser connected across the interrupter contacts of the low-tension windings of a magneto armature. W. S. (OHIO)

(a) The testing of high-tension magnetos is an elaborate process if a comparison is to be made between different makes. One method is to operate the magneto at from 200 r.p.m. to 4500 r.p.m., putting high-tension spark through the spark plug in an air chamber subject to pressure of 75 pounds per square inch. If no missing occurs throughout this range of speed at that pressure the voltage can be said to be good. On a magneto the difficulty will probably be with

operation at low speed. Then the high-tension current should be taken with oscillograph and, in general, the spark giving the highest current will give the most satisfactory ignition. These currents, as a rule, run from 0.03 to 0.06 amperes. An examination of the mechanism and construction of the circuit breaker and condenser and general insulation should also be made for purposes of comparison. (b) There seems to be a misapprehension as to the possibilities in this direction. There is nothing that can be put in series with a resistance but will take up some of the voltage. This would not be the case if there was any inductance of any value in the lamp itself. Theoretically, it would take an infinite capacity to run in series with the lamp to make it burn at normal brightness. If we assume that a nearly normal brightness is obtainable if we have 100 volts instead of 110, it apparently would take about 100 micro-farads. (c) There are a variety of ways of measuring capacity; the simplest, if the capacity is of any size, is to put a condenser across an alternating-current circuit. The following formula will give the value of the capacity if the current and the voltage can be measured and the frequency is known:—

$$C = \frac{I}{E\,2\pi f}$$

where C = capacity in farads, I = currents in amperes, E = potential in volts, f = frequency.

(d) The purpose of the condenser connected across the interrupter contacts of a magneto armature is to relieve sparking at these contacts. A circuit of inductance cannot be interrupted instantaneously at a contact and a temporary arc will form, which will not only burn the contact but reduce the rate of change of current in the circuit, due to the arc hanging on longer than is desired. If a condenser is put around the contacts the current at the moment of opening of the contacts goes into the condenser for a short interval, allowing the contacts to get open far enough that the arc is not formed. Then the current drops off in value very rapidly, thereby producing a sudden rise in the high-tension circuit. If any kind of a circuit-breaker mechanism could be devised which would open the circuit instantaneously without an arc there would not be any necessity of any condenser. In a way the condenser serves the same kind of purpose that the extension of a water pipe above the spigot serves in producing an air chamber which cushions the water hammer in case the water is turned off too suddenly. R. P. J.

1402—Disconnecting Transformers—In cutting a transformer out of service, or switching through transformers in case of a short-circuit on the line, should the high or low-tension switches be pulled first? A. P. S. (CAL.)

Switching on the high-voltage side causes greater voltage surges than does low-voltage switching. On the other hand, switching on the low-voltage side requires the breaking of larger currents than does high-voltage switching. Whether switching is done on high or low-voltage sides of transformers is a matter of choice between two evils. Surges caused by high-voltage switching are of the same order as those caused by arcing grounds and indirect lightning strokes. Transformers that are capable of withstanding the latter should successfully withstand the former. Therefore, so far as the transformers are concerned, it would seem proper to have the high-voltage switches open first. However, the size and construction of the switches, as well as the relative values of the voltages and currents, should be considered before deciding. J. F. P.

1403—Testing Instruments—Question No. 1373 prompts me to ask what instruments you would advise including in a set for testing induction motors and the usual alternating-current equipment found in an industrial plant? By testing, I mean trouble testing only. Would you advise using an ohmmeter for keeping track of the condition of motor coils, etc.? Voltage of motors in question range from 110 to 2200. D. D. S. (CAL.)

Where alternating current only is available, an outfit for trouble testing should consist of a lighting-out line, as described in answer to No. 1373, for locating grounds. For keeping track of the condition of motor coils a megger is preferable to an ohmmeter. A 100-200 alternating-current voltmeter, an alternating ammeter (10-20 amperes) and a compass are very convenient and easily used. With them such troubles as wrong number of poles, phases out of balance, open circuits, short-circuits, reversed coils and almost any other trouble that is liable to happen can readily be located. F. L. B.

1404—Motor With Shunt Circuit Open—What factors or load conditions might limit the speed of a commutating-pole shunt motor whose shunt field circuit was interrupted? K. F. H. (PA.)

When the shunt field is opened there is a sudden rush of current which will cause the brushes to spark badly and the commutator to flash. The speed will immediately increase and theoretically would only be limited by the residual magnetism and by friction. However, before that point is reached the armature will probably give away mechanically. For example, consider a 10 hp, 1150 r.p.m., shunt-wound motor. The maximum safe operating speed would be approximately 2200 r.p.m. At some speed between 2700 and 3000 r.p.m. the coils would begin to shift, throwing the armature out of balance and causing severe vibration. Then the bands would give away, allowing the coils to spread and wreck the armature. H. L. S.

1405 — Blue-Printing Machine — We have a 110 volt, 25 cycle, arc light blue-printing machine, and would like to know if we could use a nitrogen lamp in place of the arc light. If so, what candle-power would be best to use? A. H. A. (ILL.)

The light of the Mazda C lamp is not sufficiently actinic to warrant using it in preference to the arc lamp in blue printing. Blue prints can be made with Mazda C lamps, but for equal printing speed a greater expenditure of energy is required than is needed with the arc lamp, as relatively less of the energy is radiated in the ultra-violet region of the spectrum. W. A. M.

1406—Use of Rubber-Insulated Cables—In Foster's "Electrical Engineers' Pocket Book," 6th edition, p. 1083, the statement is made that paper-insulated submarine cables are taking the place of rubber-insulated submarine cables. To what extent have paper-insulated cables replaced the rubber-insulated cables for underwater service? A. G. (VA.)

This question evidently considers only telephone cables and not cables designed for transmission of electric power, since the contex of the reference deals only with telephone cables. We believe that paper-insulated cables are hardly to be recommended except under certain conditions in preference to a rubber-insulated cable. In certain cases where a short length of submarine telephone cable is connected to a long aerial line or length of cable where Pupin coils are used it might be necessary to use paper-insulated cable to reduce the capacitance to a minimum and secure consequent further extension of the distance over which speech can be clearly transmitted. However, in most cases the greater capacitance of rubber-insulated cables would not materially effect telephonic service, and in such cases rubber-insulated cable would be preferable to paper-insulated cable. The use of paper-insulated submarine telephone cables has, in general, been limited to these special conditions. R. E. D.

1407 — Turbogenerator as Synchronous Condenser—(a) Is it possible to use turbogenerators for power-factor correction, the steam from the turbine being used for steam heating or with the turbine running condensing? (b) Is it possible or advisable to use a turbogenerator in this way with the turbine blades running in a vacuum and with no steam being admitted to the turbine? Please give a description of how it is done. C. F. (CAL.)

If a synchronous machine operates as a synchronous condenser, the fields must be over-excited, and if the power-factor is so low there is danger of overheating unless the rotor is proportioned for the heavy exciting currents. It is therefore advisable either to determine what the temperature of the rotor will be by the increase in resistance method, or obtain the advice of the manufacturers as to whether or not the heating will be prohibitive. (a) We understand this to mean that a certain amount of true power will be taken from the unit in addition to the wattless k.v.a. which will be used for power-factor correction. If the resultant power-factor at the terminals of the stator of the generator is 40 percent or less, the excitation will be practically the same as would obtain with the generator operating as a synchronous condenser running idle, the same total k.v.a. being taken from the stator in either case. The method probably would not be an economical one, since the turbine would be considerably underloaded, and therefore a large amount of steam per kw-hr. would be needed. (b) If no steam flows through the steam turbine, and air at atmospheric pressure is contained in the turbine, the windage losses in the turbine would, in all probability, be great enough to produce prohibitively high temperatures. One alternative is to leak a small amount of steam through the turbine continuously, sufficient to overcome friction. The second alternative is to maintain a high vacuum within the turbine, when the turbine may be operated without steam. It is then important to keep the vacuum pump running and to have a gauge suitably provided for the purpose of determining whether or not a high degree of vacuum

is maintained. The third alternative is to disconnect the turbine from the generator entirely, in which case suitable provision must be made for supporting the shaft adjacent to the turbine, and to furnish a supply of oil or water, as may be needed, for cooling the bearings. Means must further be provided in the latter case for starting the generator. In general, there should be little difficulty from hunting, especially if the rotor is made of solid material, as is now general practice. C. J. F.

1408 — Commutating-Pole Motor — Why is it that a commutating-pole, shunt-wound, direct-current motor will alternately pick up and release its load when the brushes are shifted about five degrees either way from neutral position? The disturbance is quite violent and, under these conditions, it is impossible to operate the machine. No sparking results from the brushes being off neutral. J. H. B. (COLO.)

When the brushes of a commutating-pole motor are shifted against the direction of rotation, the motor will tend to become unstable, and alternately pick up and drop the load, especially if the motor is driving an inertia load. This is because of the weakening of the main field by the back armature ampere-turns and the effect of the short-circuited armature coils. This causes the speed to rise with the load. However, if the brushes are shifted forward the result would be just the opposite, so that the motor should be perfectly stable. The brushes on a commutating-pole motor should always be kept at the neutral position. C. G. L.

1409—Electric Heaters—The writer is an electrician in a western sawmill, which has an automatic air trimmer to trim the lumber the required length The saws are driven from a line shaft which is run by a motor, and the saws are raised and lowered by air cylinders which are connected to the arbor that carries the saws by a rod. The cylinders are operated by a wire from a cage where a man sits and pulls the right wire, which opens the valve in the air cylinder. When the air pressure is off, the saw drops and cuts off the lumber. When the valve is closed again the air forces up the piston and raises the saw again. We had quite a lot of trouble last year with the air freezing in the cylinder and stopping the piston from working. Would like to know if we could not wrap the cylinder with a resistance wire to keep it warm with electricity, and if common iron wire would not answer the purpose. There are about 18 cylinders, each 12 inches long and 14 inches in diameter. We have 110, 220 or 440 volt alternating current available; also have 550 volts direct current which could be used. E. M. D. (WASH.)

It is perfectly feasible to apply heat in this way to a cylinder, and the only difficulty will be to determine the proper quantity. It is impossible to make an accurate estimate, as you have not supplied us with any definite information regarding the quantity of air or the pressure used. We would estimate, however, that an input of from 600 to 1000 watts, applied in a coil of wire wrapped around the outside of the cylinder, should be sufficient to prevent any serious freezing. If this is not sufficient, it will be an easy matter to rewind the coils, if they were properly constructed. Iron wire would be suitable, but it is open to criticism on account of its high temperature coefficient and also because of the danger of rusting. We would recommend the use of German silver or a nickel copper alloy, such as "Advance." The wire should be wound the full length of the outside of the cylinder with turns fairly close, so that reasonably heavy wire may be employed. The temperature is relatively low and it will probably be satisfactory to wind a wire over a layer of asbestos paper one-sixteenth inch thick wrapped on the surface of the cylinder. Another layer of paper over the resistance wire and held on by a layer of banding wire or a sheet-tin covering will protect the resistance. The layers of asbestos and the surface of the pipe should be thoroughly brushed with shellac and the outer surface thoroughly painted with it in order to make the entire heater water-proof. When the operation is first started there will probably be some smoking, but this will not do any damage. If possible, 110 volts should be used in order that there may be little danger to the workman in case of a ground. The method outlined above could be greatly improved upon if such a device were to be manufactured in quantities, but we believe it will serve the purpose, especially in view of the fact that it is to be used for only three or four months each year. F. T.

1410—Cement Dust on Insulators—We have a 13 000 volt transmission line which passes by a large Portland cement mill. The dust from this mill deposits on the insulators, and in the course of six months to a year the insulators become sufficiently coated to ground the line and put it out of commission. I would like to know if you have any references on methods of protecting transmission lines against such trouble. G. B. D.

We never heard of any permanent remedy. The use of larger insulators will postpone the trouble and render the interval between cleaning longer. A solution of either muratic acid or oxalic acid is useful in cleaning the insulators. The use of 60 000 volt insulation on a 13 000 volt line for a distance of one mile each way from the cement plant ought to render troubles very infrequent. R. P. J.

1411—Pipe Thawing—Size of pipe to be thawed, two inches; length of pipe, 2400 feet; available voltage, 88, 174 or 350; available power, 128 kw. What is the size of iron or the cheapest wire that would thaw this pipe? The transformers are located on one end, so that 2400 feet of wire is all that is required. Cost of current is no object. J. H. B. (COLO.)

We assume this is wrought-iron pipe. The calculated resistance of iron pipe, 2400 feet long, is 0.46 ohms. This undoubtedly is the minimum resistance possible and the actual resistance may be several times this, due to resistance of joints. It is probably desirable to keep the resistance of the supply wire down to a value of approximately 0.46 ohms, in order that the loss in the supply wire shall not be greater than the loss in the pipe. Using this limit, probably the loss in the supply wire will be much less than that in the pipe. To meet this resistance will require No. 3 copper wire with a weight of about 380 pounds. Iron wire for this resistance would have to be twice the size, or No. 0000. Probably 350 volts will give the most satisfactory results, as the current cannot be over 400 amperes with the above resistances. In fact, unless the joints in the pipe have very low resistance, this voltage may not be sufficiently high. W. R. W.

1412—Rewound Field—Please explain what effect it would have on an armature if the field of a motor were wound with more turns than it was before. Would this heat the armature or the field, or would it require higher voltage to run at same speed? F. K.

The speed of a motor or the voltage of a generator depends upon the magnetic flux, and this in turn is a function of the ampere-turns in the exciting windings. Let E equal the voltage over one coil; I the current; N the number of turns; R the resistance; and r the average resistance of one turn. For a shunt coil,—

$$I = \frac{E}{R} = \frac{E}{Nr}$$

The exciting ampere-turns

$$NI = \frac{NE}{R} = \frac{NE}{Nr} = \frac{E}{r}$$

The number of turns appears in both the numerator and denominator and cancel, leaving the excitation proportional to voltage and the average resistance per turn. However, if N is increased, the thickness of the coil is also increased. This gives a larger mean turn, and a higher value for r. The excitation of the coil will thus be changed, but usually not enough to noticeably effect the characteristics of the machine unless there is a considerable difference in the number of turns. The copper loss will be less and the radiating surface greater, thus the coils should run cooler. Copper loss =

$$E\,I = \frac{E^2}{Nr}$$

For the same impressed voltage and size of wire, the ampere-turns are approximately independent of the number of turns in the coil and the watts loss in the coil vary inversely as the number of turns. H. L. S.

1413 — Hysteresis Loss — Is the hysteresis loss per revolution obtained in rotating an iron cylinder about its axis, in a uniform magnetic field perpendicular to that axis, the same as the hysteresis loss per cycle obtained by keeping the cylinder at rest, and letting the field alternate so as to give the same extreme values of magnetization? Can you refer to experiments on this point? J. S. (PA.)

An iron cylinder rotating about its axis in an extensive uniform magnetic field will have a uniform magnetic intensity throughout the cylinder. As the cylinder revolves, the magnetic density will change in direction, but not in magnitude. At low induction this will result in a hysteresis loss somewhat smaller than the loss caused by pulsating flux. At high induction the hysteresis loss is practically zero. These phenomena are covered in "The Magnetic Induction in Iron and Other Metals," by Mr. A. J. Ewing; price $4.00. L. W. C.

CORRECTION

In the JOURNAL for Nov., '16, p. 555, the second line under Fig. 1 should read "were done before soldering, the excess solder might fill up the."

FINANCIAL SECTION

To Our Subscribers:—It is our aim in this financial section to publish information regarding financial matters which will be of practical interest and value to Journal readers in general. We would like to have your comments on what has been published so far and suggestions as to future issues. If you have any questions on the subject, do not hesitate to send them in. The financial section is written by the best public utility writer on Wall Street, a recognized authority in the field whose writings are considered the final word by the largest brokers on the Street. We want to make the financial section just as helpful to you as the technical section. Won't you help us make it just what you want by writing us in detail?

BUYING SECURITIES

Many persons believe that there is something mysterious about the purchase of stocks and bonds, and for that reason refrain from investing their surplus funds in securities simply because they do not understand the methods by which stock and bond purchases are made. The purchase of securities, however, in actual practice is as simple as the purchase of almost any other commodity and is carried on much in the same way. It is as easy to secure actual information on investment securities as it is on other commodities offered for sale, and the market price of any investment security may be secured as quickly and easily as that of grain, metals or other articles of daily use.

In buying securities the first thing to do is to select your security. The intending purchaser will find that any responsible bond dealer, broker or the local banker will be glad to help him do this. On any security which is worthy of the name of "investment" full details of past and present operations can be secured without trouble. Earnings over a period of years may be obtained in the case of an established corporation, and it should be remembered that the bonds and stocks of new companies usually are not entitled to the name of investments, but partake more largely of the nature of speculation, unless they are consolidations or reorganizations of old companies.

In the minds of those who are not familiar with investment affairs there is too often a prejudice against the name of "stock broker." These persons fear that when they deal with a stock broker they will occupy the position of a lamb before a shearer. There is no greater mistake. By far the greater number of stock brokers are honest; in fact, as a whole they are probably the most honest class of business men in the world. They must be such, for their business is built entirely on the confidence of their customers. Here and there a black sheep may be found, but he will remain no longer than the time his true character is learned. In making investments deal only with members of the recognized stock exchanges of the country, with members of the Investment Bankers' Association of America or with your banker. If a purchaser of securities should find that any of these men have misrepresented the actual investment value of securities to him his complaint to the boards of governors of the exchange or of the association will receive prompt attention.

In the case of the New York Stock Exchange and almost all other exchanges the burden of proof in any complaint by a customer against a member of the exchange is on the latter. No matter how a customer may treat his broker, the latter has no redress before the board of governors, but the customer may at any time appeal to the governors against his broker in case he feels that he has been aggrieved. No one, no matter how inexperienced he may be in the purchase of securities, need have fear that he will not be treated fairly by the broker to whom he intrusts his order, if he will only use due care in selecting the broker and see that he is either a member of some recognized stock exchange or affiliated with the Investment Bankers' Association of America.

In making a purchase of stocks the charge on the New York Stock Exchange for listed stocks is one-eighth percent, or 12.5 cents a share, on lots of 100 shares or more. On unlisted stocks the commission is usually one-fourth percent, or 25 cents a share, except in the case of the high-priced oils or industrials, when the commission will be higher. Stocks are bought "flat," that is, with the dividend included in the pur-

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chase price, except in the case of some few preferred stocks, which may be quoted "and accrued dividend," meaning that the dividend accrued from the date of the last payment to the time of purchase is added to the quoted price for the stock.

All bonds and notes are purchased "with interest," which means that to the price quoted for the bond or note will be added the interest accrued on the security from the last interest payment to the date of purchase. In the case of bonds or notes on which interest has been defaulted, or in other words, where the issuing company has failed to pay the specified interest, the sale is made "flat," or with all accrued and unpaid interest included in the purchase price. However, no reader of this will be apt to purchase any defaulted bonds or notes, as these appeal only to the speculator.

The purchaser of bonds or notes "with interest" or of preferred stocks "with accrued dividends" must not feel, however, that he is losing the amount added to the purchase price of his security. In the case of bonds or notes the interest is represented by the semi-annual coupon attached to the bond or note, and when this falls due the holder deposits it in the bank, receiving the full amount of money represented by the coupon, and thus is returned to him the money paid for the accrued interest at the time of purchase. In the case of stock purchased with accrued dividend added, at the regular time of dividend payment will be received a check for the full amount of dividends for the quarter or the half year, and so the holder will have returned to him, when he cashes his dividend check, the additional money paid at time of purchase.

Interest on bonds is represented by the attached coupons, and these must be detached and deposited for payment to secure payment of the interest, unless the bonds are registered as to interest, when the interest will be mailed to the holder of the bond in the same manner as would be dividends on stocks. Some bonds may be registered both as to principal and interest and others may be registered as to principal only. The registration of a bond is simply the act of having the bond or bonds registered in the name of the holder by the trustee of the mortgage securing the bond. With this done the bond is not negotiable unless it is endorsed by the owner. Unregistered bonds pass from seller to purchaser without endorsement, so that registration is a protection against theft or the falling of the bond into unauthorized hands in case it should be lost. Dividend-paying stocks sell "ex-dividend" usually from fifteen to twenty days prior to the payment of the dividend, although in the case of some stocks this period may be 30 days or even more. This means that the dividend checks for the forthcoming dividend payment will be mailed to those persons in whose names the stock stood at the time of its becoming ex-dividend. As an instance, if the regular quarterly dividend on a stock were payable January 1 to stock of record December 15, only those persons whose names were on the stockbooks of the company as holders of the stock on December 15 would receive the dividend checks January 1. The holder of stock purchased and transferred after December 15 would not receive a dividend check until the next regular quarterly period of payment on April 1. For this reason the purchaser of a dividend-paying stock should have it transferred into his name as soon as possible, and in doing so should give his full name, not initials, as the latter are not accepted for the purpose of making out stock certificates, and also his postoffice address, so that dividend checks and other communications from the company will reach him promptly.

In regard to the registration of a bond, this is entirely optional with the holder in the case of such bonds as may be registered, as not all companies register their bonds. As already said, registration is a protection against loss in case of a stolen or lost bond, as the registered bond cannot be negotiated without endorsement. The unregistered bond is more negotiable and, where bonds are kept in a safe place, there is really little necessity for their registration.

Having selected the security get either your banker or a broker to secure a quotation on it for you, always remembering that, while bond quotations are usually fairly stable and vary but little from day to day, there will be much more variation in the price of stocks and a quotation given one day may not be good at all the next, as the stock may be either higher or lower. With high-grade investment stock issues the quotations, as in the case of bonds, will vary but fractionally, while with the more speculative stocks there may be a difference of a dollar or more per share in the price tomorrow compared with that today. In the purchase of either a bond or of stock the buyer should know just what return in the way of interest or dividends he will receive on the money invested in the securities. This is quite easy to determine in the case of stocks, but much more difficult in that of bonds. To calculate the rate of income which will be received on stock it is only necessary to divide the amount of dividends received in a year on a share by the price paid per share for the stock and the result will be the rate percent of income. As an instance, a purchase of stock paying six percent dividends a year is made at 90. Dividing the $6 dividend received per annum on each share by the price of $90 a share paid for the stock the result would be 6.66, which would mean that the security holder would receive a return of 6.66 percent on the money invested in the stock.

Bonds having a definite maturity which stock does not have makes the calculation to determine the yield on bonds much more intricate. In fact, bankers and brokers in finding the yield of income on bonds always use a book of bond tables prepared for this purpose by the aid of logarithms, thus securing the exact yield. It will be seen that in case a bond is purchased below its face value and held to maturity, in addition

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to the interest regularly paid on the bond the holder at its maturity will receive a sum larger than was paid for the bond, this excess payment depending on how much below face value the purchase of the bond was made. If the bond was purchased above its face value the sum paid at maturity would likewise be smaller than that originally paid. It is not probable that the average investor will ever buy a bond above its face value as, in fact, most bond dealers discourage the purchase of such bonds except by investors who are versed in the theory of amortization and other matters having to do with such investments.

Roughly speaking, the income yield of bonds may be figured as follows:—Purchasing a 5 percent bond at 90, having ten years to run from the time of purchase to maturity, would mean that on the purchase price, without reference to maturity, the income yield would be 5.55 percent, figured in the same way as the income yield on stock. But within ten years the bond will be paid at its face value, so that for a thousand dollar bond for which $900 was paid the holder will get $1000 at maturity, or $100 more than was paid. This would be $10, or 1 percent, a year, so that the income yield on the investment in a 5 percent bond at 90, having ten years to run, would be approximately 6.55 percent. Of course, to secure this yield the purchaser would have to hold the bond to maturity, but he would usually find that as the bond approached maturity it would reflect in its market price the additional value by reason of the closer maturity, so that, even if he sold after holding five years, he would receive a price for his bond which would make his income yield approximately that which he would have received in case he should hold the bond to maturity.

Having selected the security, learned the price, income yield and other particulars concerning it and the issuing company and placed the order for the security with the banker or broker, the payment will come next. This may be either in full, on partial payments or by depositing the purchased security for a part of the purchase price, paying a specified amount in cash. When the bond or stock is paid for in full or "taken up," in the parlance of the dealer, the only details to be attended to by the purchaser before giving his check or cash for the security is to see, in case of a bond that it is actually the security bought, that all unmatured coupons are attached and that the bond is not stamped or defaced in any way which might impair its negotiability. These details, however, need bother the customer little, as they will already have been attended to by the banker or broker. In the case of stock it is well to see that it has been issued in the proper name and that the transfer office of the issuing company has the postoffice address of the owner correctly, so that there may be no delay in receiving dividend checks or other communications from the issuing corporation. These details being looked after there is nothing more for the cash purchaser to do but to take away his stock certificate or bond and put it in a safe place, preferably a safe deposit box.

In the case of stock or bonds bought on the partial-payment plan the seller holds the security until full payment is made, the buyer making an initial payment, usually 20 percent of the purchase price, and then paying an agreed sum each month until the full amount is paid, when the purchased securities will be delivered. All interest and dividends on the securities so bought belong to the buyer, and when final settlement is made he should be careful to see that he has been properly credited with such dividends or interest. The seller will charge the buyer interest on the deferred payments, but the dividends or interest received will more than offset this interest charge. The purchaser of stock on the partial-payment plan should always make a careful investigation of the character of the selling firm before making his purchase or sending any money.

There are a number of reputable houses which will sell securities on the partial-payment plan, but there have been many losses to investors who accepted at their face value glowing advertisements of the advantages of such purchases without investigating the reliability of the advertiser. There have been instances where such advertisers have collected hundreds of thousands of dollars from innocent clients and also have received large sums in partial payments and then, when delivery of securities were insisted upon, have quietly stolen away, leaving their clients without either cash or securities. Other houses doing business on the partial-payment plan sell the securities to their customers without owning them, or in other words "bucket" the orders, hoping that by the time full payment is made and the delivery of the securities is at hand that their market price will have declined and the stocks or bonds be bought for delivery to the purchasers at a lower price than that at which they sold. No reputable broker or banker would be guilty of such a practice, but the only safe way for a would-be purchaser of stocks on the partial-payment plan to do is to act only after he has made a full investigation into the reliability of the firm offering to sell securities in this manner. Any banker can easily learn the standing of any investment firm in the country, and no matter how glowing may be the promises held out always remember not to buy securities from a house which cannot give reputable bank references. After you get the references also don't fail to write and ask the standing of the firm, and if the answers are not satisfactory in every way drop negotiations at once.

One of the most satisfactory ways in which to purchase securities where they are not paid for in full and taken up is to ask a banker to make a collateral loan on them. All banks make collateral loans; in fact, they are the most satisfactory loans a bank can have, especially where the collateral has a ready market. The term "collateral" in a banking sense is applied to the securities or other papers deposited with a banker to secure a loan made on them as security. In New York the banks almost entirely confine their collateral loans to securities listed on the New York Stock Exchange, this being done because the loans are payable upon "call," or immediately on demand, and there must be an instant market for the collateral in case the loan is not paid and the collateral taken up. Because of this fact New York bankers charge a much smaller rate of interest on loans than do interior banks which loan largely on unlisted collateral. While the interior bank will charge 6 percent on a collateral loan the New York banker will charge on a collateral call loan at present not more than 2 percent interest, but such a rate is not available to the small borrower, even in New York, on listed collateral. These call loans are made in hundreds of thousands or even millions of dollars by the large brokerage firms, each loan in the bank representing possibly several hundreds of individual margin transactions by the broker, who has lumped into one great call loan the many amounts owed him on stock purchased by his customers. The broker, however, will charge his customers from 4 to 5 percent interest on the money owed to him by them.

The transaction by the small investor in making a collateral loan with his local banker will be carried on substantially as follows, and it will be seen that such a loan gives the owner of the security all the advantages of the partial-payment plan, combined with the knowledge that his stock is in safe hands and held for him until such time as he may pay up his loan:—"A" buys 25 shares of stock at 90, this transaction representing an expenditure of $2250. "A" goes to his banker and asks the latter if he will make him a loan on the 25 shares. The banker says that he will do so, taking the stock at 70. This means that "A" must pay of his own money $20 a share on the stock and the banker will then loan him $70 a share, taking the stock as security for the loan. "A" endorses the stock in blank on its reverse side, and he also will usually be called upon to make a power of attorney giving the banker full control over that particular stock certificate, the number of shares and the serial number of the certificate being expressly specified in the power of attorney. "A" will sign a note for $1750 to the bank, and the stock and power of attorney will be attached to this note. The note will be of the usual collateral form, the length of which may sometimes frighten the uninitiated, but so long as the terms of the note are complied with there need be no uneasiness in regard to its many provisions. With this transaction completed "A" will have paid $500 of his own cash on his 25 shares of stock and will owe the bank $1750, on which he will probably be asked to pay 6 percent interest per annum. At any time he may pay off a part of the amount of the note, and by such payments he may in time pay the full amount and have the stock free of debt. Each payment so made will of course reduce his interest charge at the bank. The note may be either for a specified time or on demand. Many bankers, even in the country, prefer demand notes on collateral loans. Such a transaction as this may often prove profitable to the borrower in the way of interest. In the above instance suppose that the stock on which the money was borrowed pays dividends at a 6 percent rate. Thus the 25 shares would return $150 a year in dividends.

The amount borrowed from the bank at 6 percent was $1750, and the annual interest charge on this sum at 6 percent would be $105. The actual investment in the stock, aside from the loan, is $500, so that on this $500 the borrower would receive $45 a year. In other words, on the $500 invested he is getting a return of 9 percent. The dividends on stocks or bonds may thus be used not only to provide for the interest payments on the money borrowed, but also to reduce the principal of the note.

Almost any broker will arrange for a purchaser to carry his stock with a banker in case the purchaser desires this done. The broker will probably not charge anything for this service, although in some cities the brokers make a small charge for making or renewing bank loans. In placing these loans the broker will either carry the loan in his own name or arrange for the note to be signed by the owner of the stock. It is always better for the owner of the stock in making loans through a broker to sign the bank note, as this is evidence of the ownership of the equity in the stock deposited as collateral.

As already said, the usual charge made for the purchase of unlisted stocks by a broker is 25 cents a share. This commission is added to the actual price at which the stock was bought by the broker and is payment for his services in arranging the loan. On the New York Stock Exchange the commission is 12.5 cents a share, but this commission applies only to round lots of 100 shares. When less than 100 shares or "odd lots" of stock are purchased the buyer in effect pays 25 cents a share commission. When an order is placed for an odd lot of a stock listed on the New York Stock Exchange the broker will watch for the first sale of this stock to show on the tape of the stock exchange ticker after order has been placed. Then the broker will confirm the sale of the odd lot to his customer at one-eighth of a point above this price, which with the commission added will make one-quarter of a point. The same commissions are paid in the selling as in the buying of stocks, and the seller of listed stock receives one-eighth point less than the last sale of a round lot of that particular stock to show on the stock exchange ticker.

Substantially the same commissions are charged for the purchase or sale of bonds as for stocks. In a purchase or sale of listed stocks or bonds made through a member of the New York Stock Exchange, the buyer or seller will receive from his broker a confirmation of the sale, made out on a regular form blank, giving the name of the stock sold or bought, the price, the commission, the time at which the sale or purchase was made on the floor of the exchange and the name of the broker buying or selling the stock. By this means the buyer or seller of stock is always able to trace his transaction in case any dispute over the price arises between him and his broker. So far as possible all safeguards are thrown around the buyer or seller of securities on reputable stock exchanges and, as already said, in case of complaint the burden of proof is always on the broker to show that he is not guilty of the charge made. There is no business in which the element of personal confidence enters so largely as is that of dealing in securities, and no matter how inexperienced an investor may be he may always be certain of receiving only the fairest of treatment so long as he entrusts his business to reputable firms. No matter whether the amount of money to be invested is large or small equal consideration will be shown to a customer by reputable brokers or bankers, and in these days no one need have the least fear of doing business with such houses, as the small investor is always welcome, for he may grow into a large investor in time.

PACIFIC GAS & ELECTRIC

Before the first of the year the second and third units of the Bear and South Yuba hydroelectric developments of the Pacific Gas & Electric Company will be in operation. These two plants will add 33 333 horse-power to the generating capacity of the company. Including the Drum hydroelectric plant, which has been in operation for several years, the company will have 66 666 horse-power at this development and a total of generating capacity on the entire system of 265 250 horse-power. No greater quantity of water will be required for the generation of current at the two new plants, as they use the water which has already passed through the turbines of the Drum power station. The height of the Lake Spaulding dam is being increased 35 feet, bringing it up to 235 feet and increasing the storage capacity 50 percent. This dam will be completed December 1. All the current from the new plants will be utilized at once, partly by absorption through new business and partly replacing steam generated power. In the spring of 1917 construction will be started on a fourth generating station of 33 333 horse-power for this development, enabling the company to make the fourth successive use of the same water.

The company is preparing to spend about $225 000 in enlarging its irrigation system in Placer county, utilizing the water from Lake Spaulding after it has served to produce power. A 78 mile transmission line to Stockton is being constructed, thus giving a duplicate power line into the most prolific power-producing territory served by the company. This line was constructed at comparatively low cost, as the company purchased 2 000 000 pounds of copper before that commodity began its rapid advance in price.

Pacific Gas & Electric Company on January 1 will take over Oro Electric Corporation, the physical properties of which as of February 1, 1914, were appraised by independent engineers at a value of $3 200 000. Since that time new construction has added to this valuation. Pacific Gas & Electric is securing this property for approximately $1 600 000, all of which has been advanced from current funds of the company. Oro Electric in 1917 is expected to contribute around $160 000 net profit to Pacific Gas & Electric. So far the income account of Pacific Gas & Electric has reflected only the carrying charges on the property as, while the properties have been operated by the old company for the account of Pacific Gas & Electric since February 1, 1916, the latter has included no offsetting income in its earning statements to balance these carrying charges. Oro Electric Corporation properties will fit in admirably with the Pacific Gas & Electric system, and it controls water-power sites with possibilities of future hydroelectric development totaling in excess of 130 000 horse-power.

SUPPLEMENTS TO THE DECEMBER, 1916, ISSUE

With the present December, 1916, issue of THE ELECTRIC JOURNAL are included two supplements,—the "Three-Year Topical Index" and the "Title Page and Table of Contents for 1916." As soon as the December issue has been read, the copies for 1916, with Index and Table of Contents, may be sent in for binding, prepaid. The price for binding is $1.50 per volume, prepaid. All volumes are bound in our standard half Morocco with gold lettering.

PRICES OF BOUND VOLUMES

For the present, the prices of bound volumes of THE ELECTRIC JOURNAL will be as follows for volumes III–1906, IV–1907, V–1908, VI–1909, VII–1910, VIII–1911, IX–1912, X–1913, XI–1914, XII–1915 and XIII–1916:—

Eleven different volumes ...	$34.00
Ten " "	31.00
Nine " "	28.00
Eight " "	25.00
Seven " "	22.00
Six " "	19.00
Five " "	16.00
Four " "	13.00
Three " "	10.00
Two " "	7.00
Single volumes	4.00

Special prices on bound volumes in combination with subscriptions to the JOURNAL and other technical books will be quoted on request. Volumes I–1904 and II–1905 are no longer available.

PERSONALS

Mr. Nelson S. Moore, assistant general manager of the Electrical Engineers' Equipment Company, Chicago, has severed his connection with that company to become sales engineer for Lewis & Roth Company, Philadelphia. Mr. Moore was with the Electrical Engineers' Equipment Company for over five years, and previous to that was with Sargent & Lundy, consulting engineers, Chicago.

Mr. H. W. Flashman, who has been connected with the railway and lighting department of the New York district office of the Westinghouse Electric & Mfg. Company for a number of years, has resigned to take charge of the New York office of the Moulton Engineering Corporation, consulting engineers, of Portland, Me., with headquarters in the Woolworth building. Mr. Flashman entered the engineering apprenticeship course at East Pittsburgh about nine years ago and has been with the company in various capacities until the present time.

Prof. H. V. Bozell, dean of the School of Electrical Engineering of the University of Oklahoma, has secured a year's leave of absence to accept the appointment of assistant professor of electrical engineering in the Sheffield Scientific School of Yale University.

Mr. J. E. Fries, assistant chief engineer of the Crocker-Wheeler Company, and formerly with Westinghouse, Church, Kerr & Company, has resigned to join the staff of the Tennessee Coal, Iron & Railroad Company as chief electrical engineer.

Mr. T. B. Buck, of the Westinghouse Electric & Mfg. Company, East Pittsburgh, has resigned to enter the drafting department of the Donora Steel Company, Donora, Pa.

Mr. E. H. Jacobs has been appointed chief engineer for the Electrical Engineers' Equipment Company, of Chicago. Mr. Jacobs has been with the General Electric Company for seventeen years, more recently as designing engineer of central station control apparatus.

Mr. Walter Kleine, of the New York district office of the Westinghouse Electric & Mfg. Company, has resigned to become power apparatus specialist of the Northwestern Electric Equipment Company, of New York.

Mr. Gail Reed, general sales manager of the Walker Vehicle Company, of Chicago, has joined the organization of the Anderson Electric Car Company, of Detroit. Mr. Reed has been actively connected with the electric car industry for over ten years with such concerns as the Wood Motor Vehicle Company, Rauch & Lange and the Chicago Electric Motor Car Company.

WESTINGHOUSE COMPANY ACQUIRES INTEREST IN FEDERAL LIGHT & TRACTION

The Westinghouse Electric & Mfg. Company has acquired substantial holdings in the stock and other securities of the Federal Light & Traction Company. The transaction has resulted in a change in the board of directors. Mr. Guy E. Tripp, chairman of the board; Mr. Calvert Townley, assistant to the president of Westinghouse Electric, and Mr. Samuel Insull, president of the Commonwealth Edison Company, of Chicago, were elected directors following the retirement from the board of Mr. A. W. Burchard, vice president of the General Electric Company; Mr. R. E. Breed, president of the American Gas & Electric Company, and Messrs. Harrison Williams and F. L. Dame, who are closely connected with the public utility enterprises of the General Electric Company.

Federal Light & Traction has a controlling interest in twenty light, power, traction and water properties located mostly in the West.

OFFICIAL CHANGES IN THE WESTINGHOUSE AIR BRAKE COMPANY

At the annual meeting of the stockholders of the Westinghouse Air Brake Company the position of chairman of the board was created and filled by the election of Mr. H. H. Westinghouse. Mr. John F. Miller, formerly first vice president, was elected to the office of president. Mr. Miller is a native of Pittsburgh, and received his early education in the public schools of that vicinity. Upon his graduation from Wooster Academy he became connected with the Westinghouse interests, and did his first Westinghouse work for the Philadelphia Company, of Pittsburgh. He later took charge of the real estate development of East Pittsburgh and Wilmerding as conducted by the Westinghouse companies, and subsequently was identified with important banking and public utility interests. In 1899 he was made assistant secretary of the Westinghouse Air Brake Company. His fitness for large responsibility resulted in his being made vice president in 1905, including, among his other duties, special attention to the organization and development of the company's interests abroad. Mr. Miller's broad experience, sound judgment and conservative temperament as a banker, financier and accountant qualify him particularly for his new position.

Mr. A. L. Humphrey, formerly second vice president and general manager, was made first vice president and general manager of the company. Mr. Humphrey's career and achievements as a railroad official and general manager of the Westinghouse Air Brake Company are well known to railway officers and manufacturers.

Mr. Charles A. Rowan, heretofore auditor, was promoted to the position of controller, and Mr. John H. Eicher, formerly assistant auditor, was made auditor of the company.

TRADE NOTES

Harvey Hubbell, Inc., of Bridgeport, Conn., has recently published a folder describing its new reflectors for industrial lighting service. A complete line for various applications is shown. A shade holder is included as part of every reflector. Copies of this folder, including prices, will be sent on request.

The Anderson Electric Car Company, of Detroit, has purchased the passenger vehicle department of the Walker Vehicle Company, of Chicago, and will handle the manufacture and sale of these cars in addition to those already being produced by the Anderson organization.

The Kelvin Engineering Company, Inc., which became known several years ago for its revolutionizing originality in the complete electrification of Central Amistad, one of the largest cane sugar mills in Cuba, and since similarly equipped many other mills, has published a bulletin illustrating and describing some of the work it has done and the results it has accomplished. It shows by actual test data the economic comparison of modern electrification with the older steam drive. The bulletin also illustrates and describes its sugar house apparatus, multiple effects, evaporators, vacuum pans, etc. This bulletin is printed in both English and Spanish, and a copy of either will be sent upon addressing the home office, 32 Broadway, New York City.

FACTS ABOUT GEARS

Despite the fact that gears of some sort are found in almost all machinery it is safe to say that, apart from the purely technical men, very few gear users have any real conception of the minute attention to detail involved in the making of even a passable gear. In the matter of inspection alone the jigs and gages employed represent a sum of money seemingly out of all proportion to the money value of the product, and competent gear inspectors are not a drug on the market by any means; consequently their wages are a thing to be reckoned with. Of course, to the man who regards a gear merely as a toothed wheel which turns another wheel, the refinements and requirements of gear-making processes will not be of any great interest, but to the man who insists that gears shall measure up to a certain efficiency standards any authoritative information on the subject will be welcome indeed. For the benefit of the latter class of gear buyers the Van Dorn & Dutton Company, of Cleveland, O., has issued a booklet with the succinct title, "Facts About Gears." A few views showing the more important departments of the Van Dorn & Dutton plant, and two pages giving suggestions as to the selection of materials for certain qualities, heat treatment and specifications, are the only portions of the booklet which are not strictly technical. The remaining pages are packed with valuable data on gearing terms, drawings and specification formulae for every type of gearing. Nothing is omitted which might be of value to the gear buyer in making up specifications covering his particular requirements. There are 21 sections, a perusal of which will enable even the non-technical gear user to figure out specifications for any system of gears. The sections treat respectively of different type of gears, facts about gears, gearing terms, how to order gears of all kinds, spur gear specifications, bevel and mitre gear specifications, worms and worm gears, sprocket specifications, Lewis' rule for strength of gear teeth, diametrical pitch-formulae, diametrical pitch-table, circular pitch-formulae, circular pitch-table, decimal equivalents of 113 fractional dimensions of one inch, decimal equivalents of fractions of millimeters, metric pitch module, standard keyways, comparative size of gear teeth, weights of round steel, weights of metals, circumferences and areas of circles from 1/64 inch to 100 inches. As a digest of specialized gear data the booklet is worthy of a place in every gear user's reference library. Interested persons may obtain copies from the Van Dorn & Dutton Company's general offices at Cleveland, Ohio.

NEW BOOKS

"Principles of Alternating-Current Machinery" — Ralph A. Lawrence. 614 pages, 173 illustrations. Published by McGraw-Hill Book Company, New York City. Price $4.50.

This is an electrical engineering text dealing with the principles underlying the construction and operation of alternating-current machinery. It is no sense a book on design, but is based on the author's experience in teaching senior students at the Massachusetts Institute of Technology. Mathematics is used throughout the work, including graphical methods. The alternator and synchronous motor is discussed, followed by a section on static transformers, including reactance coils, three-phase transformers and different methods of connecting transformers. A chapter is devoted to synchronizing, to hunting and to power output of alternators operating in parallel, and the effect of wave form on parallel operation. Commutating poles are also discussed and illustrated. Considerable space is devoted to induction motors, including single-phase motors, with sections on singly-fed series motors, doubly-fed series and repulsion motors and compensated repulsion motors.

NEW BOOKS

"Light and Shade"—M. Luckiesh. 277 pages, 135 illustrations, 10 tables. Published by D. Van Nostrand Company, New York City. Price $2.50.

The sense of vision is dependent primarily upon the relative effects of light and shade, color vision being, as pointed out by Mr. Luckiesh, of importance principally from the aesthetic standpoint, as color-blind persons see objects almost as clearly as those not so unfortunate. The author does not, however, disparage color vision; the present work is, in fact, a companion volume to his book on "Color and Its Applications." The importance of the subject of light and shade in the author's viewpoint is expressed as follows:—"He who has learned the science of light, shade and color, who has learned to observe and record them, and has learned to manipulate them to produce various effects, has learned the means by which achievements may be obtained. He has grasped the science and is prepared to master the art."

This book is a condensed record of several years' research in the science of light and shade: some of the illustrations will be recognized by those who have heard the author lecture. While written by an illuminating engineer, it is not at all a work on illuminating engineering. Rather he has been led by his studies to analyze the fundamental principles of lighting as it affects vision, and his work represents probably the first scientific analysis of the effects of shades in correct vision.

Photographers have recognized for years that too uniform lighting is objectionable, as it does not throw the features into sufficient relief. A point light source, on the contrary, is objectionable, as it produces too harsh shadows. What is desired is enough direction of light to bring out the correct modeling of the features, with at the same time enough dispersion of light to produce softness and roundness. The application of these same principles to all lighting is made in detail by Mr. Luckiesh's analyses

The book is replete with illustrations representing numerous experiments on light and the resulting shadows. The degree of contrast between light and shade in nature is studied and analyzed at some length and incidentally compared with the degree of contrast available in painting and photography. The author explains that one of the great difficulties in obtaining suitable illustrations is due to the extreme limitations of the photographic processes as compared with the eye. Hence the contrast in shadows in many of the illustrations represents only a small part of their range as seen by the eye. The photographic plate and papers are analyzed in some detail in explanation of the short range of contrasts available by this process and of the incorrect representations of colors by all ordinary plates.

It would naturally be expected that the effects of too contrasting and too uniform lighting would be very manifest in sculpture and bas-reliefs. These effects are brought out excellently by the illustrations and in the discussion, which applies not only to sculpture, but to all architecture. One would hardly expect, however (unless previously familiar with the author's work) that the direction of light would have as much effect upon a perfectly flat painting as is brought out by the experiments along this line. The application of the principles deduced from the numerous experiments, as given in the chapters on sculpture, architecture, painting, photography, and the effect of light and shadow on vision, and lighting, should prove of great value to all who are interested in illuminating engineering. C. R. R.

"Radiodynamics"—B. F. Meissner. 206 pages, 112 illustrations. Published by D. Van Nostrand Company, New York City. Price $2.00.

From a wide experience as Expert Radio Aide in the U. S. Navy, the author gives a complete summary of present methods of controlling torpedoes and other mechanisms by wireless equipment from a distance. In order to make the book of value to those who have not previously studied the subject, he gives an excellent historical and physical introduction to the general subject of wireless telegraphy and wireless signals, including signals by sound and light waves through water and through the air. It is relatively easy to equip a torpedo or small boat with wireless equipment which will enable its movements to be controlled from the shore under ideal conditions, and a number of such systems are described. The difficulty comes in devising a mechanism whose movements will be free from interference from wireless signals sent out by the vessel which is being attacked. The equipment must also be extremely sensitive and at the same time must be sufficiently rugged and reliable to withstand the mechanical shocks received from the tossing of a small vessel running at high speed in the open sea, and must be sufficiently constant in action not to need adjustment. Practically all wireless receiving equipments used in telegraphy need occasional adjustment from the operator to obtain best results; this is manifest impossible in a case of a dirigible torpedo. The various types of apparatus for obtaining selectivity, as well as the other apparatus necessary for torpedo control, are described and illustrated. The descriptions apply, of course, equally well to the control of other mechanisms than torpedoes and, since the principles and apparatus used are broadly similar to those used in wireless telegraphy, the book should be of interest and value to any wireless operator. C. R. R.

"Handbook on Machine Shop Electricity"—C. E. Crewell. 461 pages, 61 illustrations, handbook size. Published by McGraw-Hill Book Company, New York City. Price $3.00.

This handbook is for the use of the practical shop man and includes such subjects which apply in one way or another to particular uses of electric power in shop operations. Numerous references to JOURNAL articles are included. The book is divided into ten sections on,—Units; Circuits; Costs; Communications and Distant Control; Current Supply; Generators and Transformers; Electrochemical, Soldering and Welding; Heating and Magnetic Apparatus; Measuring Instruments and Measurements; Motors and Applications, with a small amount of space devoted to wiring methods, and much of this refers to knob and tube wiring, which is not now considered the highest class of factory wiring. Under Communication and Control are included alarms for sprinkling systems, electric clocks, door openers, shop whistles, time-keeping apparatus, etc. While the author is particularly conversant with Shop Lighting, only a small amount of space has been devoted to this subject, merely enough to give a general idea as to the possibilities. Motors and Motor Applications are discussed at length, including methods of armature winding and numerous applications to various types of apparatus.

"Power for Profit"—Reginald P. Bolton. 8.5x10 inches, 198 pages. Published by the Devinne Press, New York City. Price $2.00.

This work takes up in detail the problems involved in the use of machinery and labor in modern buildings. The author brings out the fact that the entire cost in providing and operative equipment is seldom fully reckoned. Usually only the apparent items are considered, and all collateral expenses and other elements of costs which in the aggregate may become a serious investment burden are unfortunately overlooked. The result of such practice is a direct loss to the community and is nothing more or less than economic crime. The soundness of centralization utility service is dwelt upon, as well as the fallacy of the indiscriminate installation of isolated plants. Rather simple language has been employed as opposed to the customary technical descriptions embodied in treatises of this nature. This enables the layman, and particularly the building manager who may not be well grounded technically, to grasp the situation more easily and consequently guard against being misdirected by those who may endeavor to dispose of power plant machinery irrespective of its ultimate advantage to the purchaser. In addition to building managers and architects, central station men may examine the contents of this book with much profit. E. D. D.

"Cost Accounting"—J. Lee Nicholson, C.P.A. 6x9 inches, 327 pages, 93 illustrations. The Ronald Press Company, New York City. Price $4.00.

The more successful manufacturing corporations are those who make a practice of determining the individual costs of their various products. Much progress has been made in this direction in recent years, and many concerns have their cost statements on a very satisfactory basis. There is, however, vast opportunity for improvement by those managements which have been lacking in this respect. Numerous books on the subject of cost accounting have already been offered to the public, but a new volume with fresh material will meet with a large demand, and a review of this work furnishes conviction that it merits a place among the best reference literature on the subject. The first part of the book is given over to the fundamentals of cost systems and sets out the different wage plans in vogue, also the several bases of pursuing cost accounting. Compiling cost data, devising cost systems and plant examinations are three prominent chapters of the twenty of which the book is composed. While each plant must have its forms adapted to its needs, the author has included an extensive series of forms which should prove quite an instructive guide in the installing of a new system. The book has much to recommend it for those seeking enlightment on this branch of business which is becoming of increasing importance. E. D. D.

THREE YEAR TOPICAL INDEX

OF

THE ELECTRIC JOURNAL

WITH

INDEX TO AUTHORS

FOR

VOL. XI - - 1914

VOL. XII - - 1915

VOL. XIII - - 1916

PUBLISHED BY

THE ELECTRIC JOURNAL

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OUTLINE KEY TO TOPICAL INDEX

VOLUMES XI, XII and XIII

THIS Index, as well as the Ten-Year Topical Index, issued as a supplement to the Journal for January, 1914, is arranged according to the topical classification of subjects. The original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten-Year Topical Index and the present Index, which covers the first three years of the second decade.

Abbreviations:—*T*-Number of Tables; *C*-Number of Curves; *D*-Number of Diagrams; *I*-Number of Illustrations; *W*-Number of words; *QB*-Question Box; *EN*-Engineering Notes; *ROD*-Railway Operating Data. (The numerals following *EN* and *ROD* are volume and page numbers.) The main headings and sub-divisions are as follows:—

ELECTRICAL ENGINEERING

RAILWAY ENGINEERING

MISCELLANEOUS

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MECHANICAL ENGINEERING

ELECTRICAL ENGINEERING

GENERAL

MATERIALS

Insulation

MEASUREMENT

General

GENERATION

(AND ALL PARTS OF ROTATING MACHINES)

ARMATURES
(except commutators)

BEARINGS

COMMUTATORS and COLLECTOR RINGS

FRAME

FIELD WINDINGS

Direct Current

SHUNT AND COMPOUND

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GENERAL
(See also Theory, p. 4)

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SYSTEMS

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Overhead

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SWITCHBOARDS
General

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The History of the Lightning Arrester—A. J. Wurts. D-2, I-11, W-6500, p. 187, Apr., '16; p. 207, May, '16; R. P. Jackson. D-2, I-7, W-1870. Vol. XIII, p. 299, June, '16.

Protection of Outdoor Transformer Substations from Lightning—Q. A. Brackett. I-5, W-1380. Vol. XI, p. 409, July, '14.

Lightning Arresters for Electric Railway Equipment—Q. A. Brackett. Circuit breaker, magnetic blow-out, multipath, and condenser type arresters. I-7, W-3280. Vol. XI, p. 247, May, '14.

Charging Resistance for Electrolytic Lightning Arresters—G. C. Dill. D-3, I-2, W-790. Vol. XI, p. 251, May, '14.

Protection from Lightning and High-Voltage Disturbances—Q. A. Brackett. Lines. Station equipment. Types of arresters. I-11, W-5460. Vol. XII, p. 310, July, '15.

Protection of Distributing Transformers—Q. A. Brackett. I-2, W-1460. Vol. XIII, p. 302, June, '16.

Lightning Protection—QB, 1018, 1287.

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Lightning Rods—QB, 1260.

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Voltage Regulation of the West Penn System—J. S. Jenks. Automatic induction regulators. I-8, W-3240. Vol. XI, p. 309, June, '14.

Automatically-Controlled Feeder Voltage Regulators—E. E. Lehr and I. C. Minick. I-4, D-2, W-1910. Vol. XIII, p. 382, July, '16.

A 480-Point Testing Regulator—E. E. Lehr. D-4, I-1, W-1450. Vol. XIII, p. 227, May, '16.

Automatic Induction Regulator—QB, 1166.

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Progress in Industrial Control—F. D. Hallock. (E) W-1380. Vol. XI, p. 653, Dec., '14.

An Appeal for Controller Education—H. L. Beach. (E) W-630. Vol. XI, p. 654, Dec., '14.

An Analysis of Controller Diagram Construction—H. L. Beach. D-8, W-1510. Vol. XI, p. 666, Dec., '14.

The Magnet Switch—E. A. Hanff. Details of design and characteristics. I-15, W-2890. Vol. XI, p. 656, Dec., '14.

An Analysis of Industrial Control—A. G. Popcke. With respect to type of construction and characteristics of the motors. T-1, W-2450. Vol. XI, p. 661, Dec., '14.

Automatic Starters and Controllers—W. H. Patterson. D-5, I-14, W-1740. Vol. XI, p. 669, Dec., '14.

Control Panels for Synchronous Motors—R. L. Kimber. D-1, I-7, W-1450. Vol. XI, p. 701, Dec., '14.

The Manufacture of Electric Controllers—J. A. Blickman. I-7, W-1930. Vol. XI, p. 692, Dec., '14.

Unit-Switch Control on the New York Municipal Railway—E. Keller. D-1, I-6, W-1092. Vol. XIII, p. 462, Oct., '16.

Recent Development in HL Control—J. A. Clarke, Jr. D-1, I-14, W-1620. Vol. XII, p. 452, Oct., '15.

Low-Floor Car Control—Karl A. Simmon. The HLD Controller. D-3, I-4, W-765. Vol. XIII, p. 505, Oct., '16.

Transition in Railway Control—EN, XII,425.

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SPECIFIC APPLICATIONS
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Magnetic Controllers for Crane Motors—W. O. Lum. D-1, I-7, W-1600. Vol. XI, p. 681, Dec., '14.

The Selection of Control for Portable Drilling Rigs—W. R. Johnston. D-4, I-4, W-3700. Vol. XI, p. 720, Dec., '14.

Electric Elevator Control—H. D. James. D-2, I-3, W-2520. Vol. XI, p. 677, Dec., '14.

Control for Mine Hoists—Graham Bright. Direct-current. Alternating-current. The Ward Leonard and Ilgner systems. C-2, D-3, I-3, W-3330. Vol. XI, p. 704, Dec., '14.

Skip Hoist Control—J. H. Albrecht. For blast furnaces. C-2, D-1, I-4, W-960. Vol. XI, p. 664, Dec., '14.

Automatic Control for Laundry Machines—H. F. Boe. Driven by alternating-current reversing motors. C-1, D-1, I-4, W-750. Vol. XI, p 690, Dec., '14.

Automatic Controllers for Adjustable-Speed, D. C. Paper Machine Motors—R. T. Kintzing. D-1, I-2, W-820. Vol. XIII, p. 430, Sept., '16.

Operation of PK Control on the New York Railways—Alex. McIver. I-5, W-1350. Vol. XI, p. 570, Oct., '14.
(E) B. W. Stemmerich. W-280, p. 502.

The Control of Induction Motors for Rolling Mill Drive—Wilfred Sykes and G. E. Stoltz. By the automatic slip regulator. C-9, D-1, I-3, W-3580. Vol. XI, p. 709, Dec., '14.

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(E) Brent Wiley. W-450, p. 655.

Steel-Mill Motor Control—W. O. Lum. Automatic starters. Contractors. Relays. D-3, I-9, W-2340. Vol. XI, p. 156, Mar., '14.

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The Design and Application of Rheostats—H. C. Nagel, I-9, W-4220. Vol. XI, p. 720, Dec., '14.

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Iron Wire Rheostat—QB, 1200.

Liquid Rheostats—W. E. Thau. For controlling wound secondary induction motors. C-1, D-1, I-3, W-1610. Vol. XI, p. 684, Dec., '14.
(E) Girard B. Rosenblatt. W-380, p. 655.

Water Rheostat—QB, 1330.

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The New Code of Lighting for Factories and Other Work Places—C. E. Clewell. T-1, C-1, I-2, W-4350. Vol. XIII, p. 182, Apr., '16.
(E) Chas. R. Riker. W-450, p. 153.

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Tendencies in Street Car Illumination—N. H. Callard. T-2, C-1, I-5, W-2000. Vol. XII, p. 449, Oct., '15.
(E) W. H. Rolinson. W-500, p. 433.

Watts vs. Wallpaper—S. G. Hibben. The effect of interior colors and finishes upon room lighting. T-8, D-1, W-2015. Vol. XIII, p. 329, July, '16.
(E) A. H. McIntire. W-180, p. 323.

Flood Lighting—QB, 1366.

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Street and Industrial Lighting Units—G. W. Roosa. T-2, C-3, D-2, I-11, W-3130. Vol. IX, p. 325, June, '14.

INCANDESCENT LAMPS.

Large Incandescent Lighting Units—A. R. Dennington. The nitrogen filled tungsten. I-4, W-2330. Vol. XI, p. 306, June, '14.

The Efficiency of the Incandescent Lamp—W. H. Rolinson. T-3, C-4, I-2, W-2850. Vol. XI, p. 341, June, '14.

Results with Nitrogen-Filled Lamps—Ray Palmer. For street lighting in Chicago. T-1, W-1090. Vol. XII, p. 225, June, '15.

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